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U.S. Department of Commerce
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National Institute of Standards and Technology

Office of Applied Economics
Building and Fire Research Laboratory
Gaithersburg, Maryland 20899

Impacts of Automation and Integration Technologies on Project and Company Performance

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Foreword

Information technologies have transformed many aspects of our daily lives and revolutionized industries in both the manufacturing and service sectors. Within the construction industry, the changes have so far been less radical. However, the use of information technologies offers the potential for revolutionary change in the effectiveness with which construction-related activities are executed and the value they add to construction industry stakeholders. Recent exponential growth in computer, network, and wireless capabilities, coupled with more powerful software applications, have made it possible to apply information technologies in all phases of the building/facility life cycle, creating the potential for streamlining historically fragmented operations.

Computer, automobile, and aircraft manufacturers have taken the lead in improving the integration of design and manufacturing, harnessing automation technology, and in using electronic standards to replace paper for many types of documents. Unfortunately, the construction industry has not yet used information technologies as effectively to integrate its design, construction, and operational processes. There is still widespread use of paper as a medium to capture and exchange information and data among project participants.

Inadequate interoperability increases the cost burden of construction industry stakeholders and results in missed opportunities that could create significant benefits for the construction industry and the public at large. The lack of quantitative measures of the annual cost burden imposed by inadequate interoperability, however, has hampered efforts to promote the use of integration and automation technologies in the construction industry.

To address this need, the Building and Fire Research Laboratory and the Advanced Technology Program at the National Institute of Standards and Technology (NIST) commissioned a study to identify and estimate the efficiency losses in the U.S. capital facilities industry resulting from inadequate interoperability among computer-aided design, engineering, and software systems. That study, published as NIST GCR 04-867, estimated the annual costs of inadequate interoperability for the U.S. capital facilities industry at $15.8 billion. Approximately 40 % of this annual cost burden, or $6 billion, was attributed to inefficient business process management costs.

This study, sponsored by NIST and performed by the Construction Industry Institute (CII), focuses on that portion of the annual cost burden due to inefficient business process management functions. The technical basis for the current study stems from how closely the business process management functions used in NIST GCR 04-867 align with CII Benchmarking and Metrics task work functions. This alignment enables an analysis of how key construction industry stakeholders are using automation and integration technologies (A/I Tech) to reduce these inefficiencies at the project and company level.

This study sharpens the NIST GCR 04-867 findings by investigating two independent data sets that contain information on technology use and performance metrics from two critical components of the construction industry: industrial facilities and buildings. First,

data from 139 CII projects are summarized. Performance metrics and indices quantifying the use of project A/I Tech are discussed and the correlations identified between these metrics and indices are used to measure expected benefits. A complementary second data set from 74 Southeastern United States contractors is used to corroborate findings from the CII data. The results of this study establish that more A/I Tech use helps to improve performance. Schedule performance is strongly associated with increased A/I Tech use. Cost performance is weakly correlated with increased A/I Tech use. The study also indicates increasing deployment of A/I Tech among larger firms and projects.

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Abstract

A previous study commissioned by the National Institute of Standards and Technology, NIST GCR 04-867, estimated the annual costs of inadequate interoperability for the U.S. capital facilities industry at $15.8 billion. Approximately 40 % of this annual cost burden, or $6 billion, was attributed to inefficient business process management costs. The business process management functions used in NIST GCR 04-867 align with Construction Industry Institute (CII) Benchmarking & Metrics task work functions, enabling an analysis of how key construction industry stakeholders are using automation and integration technologies (A/I Tech) to reduce these inefficiencies at the project and company level. CII analyzed two independent data sets in this study. First, data from 139 CII projects are summarized. Performance metrics and indices quantifying the use of project A/I Tech are discussed and the correlations identified between these metrics and indices are used to measure expected benefits. A complementary second data set from 74 Southeastern United States contractors is used to corroborate findings from the CII data. The results of this study establish that more A/I Tech use helps to improve performance. Schedule performance is strongly associated with increased A/I Tech use. Cost performance is weakly correlated with increased A/I Tech use. The study also indicates increasing deployment of A/I Tech among larger firms and projects.

Keywords

Automation/integration technologies; cost savings; information technology; interoperability; practice use; schedule impacts

Table of Contents

Foreword iii

Abstract v

1. INTRODUCTION 1
1.1 Background 1
1.2 Purpose 1
1.3 Scope and Approach 1

2. SUMMARY OF TASK 1 - MAPPING 3
2.1 Interoperability Report: Methodology and Business Process Management Functions 3
2.1.1 Definition of Inadequate Interoperability Costs 3
2.1.2 Calculation of the Inadequate Interoperability Cost 4
2.1.3 Interoperability Report Survey Instruments 6
2.1.4 Business Process Management Functions 8
2.2 CII A/I Tech Task Work Functions 10
2.2.1 CII Benchmarking & Metrics Program 10
2.2.2 A/I Tech Task Work Functions 10
2.3 Work Functions Used for the Southeastern U.S. Contractor Dataset 11
2.4 Mapping 13
2.4.1 Mapping of the Interoperability Report Business Process Management Work Functions and the CII A/I Tech Work Functions 13
2.4.2 Mapping Detail 14
2.4.3 Mapping of Interoperability Report Business Process System Functions and Southeastern U.S. Contractors Work Functions 18

3. SUMMARY OF TASK 2 – DESCRIPTIVE STATISTICS 21
3.1 CII Data 21
3.1.1 Data Description 21
3.1.2 Performance Outcomes – CII Owners 23
3.1.3 Performance Outcomes – CII Contractors 27
3.1.4 Degree of A/I Tech Practice Use – CII Owners 30
3.1.5 Degree of A/I Tech Practice Use – CII Contractors 35
3.2 Southeastern U.S. Contractors Dataset 37
3.2.1 Data Description 37
3.2.2 Performance Outcomes – Southeastern U.S. Contractors Dataset 38
3.2.3 Degree of IT Practice Use – Southeastern U.S. Contractors Dataset 39
3.3 Comparison of CII and Southeastern U.S. Contractors Survey Instruments 40

4. CORRELATIONS – TECHNOLOGY USE AND PERFORMANCE 43
4.1 CII - Owners 43
4.2 CII - Contractors 48
4.3 Southeastern U.S. Contractors 52
4.4 Mapping Indices 54
4.4.1 Mapping Indices with CII Data 54
4.4.2 Mapping Indices Southeastern U.S. Contractors Data 54

5. CONCLUSIONS AND RECOMMENDATIONS 55

Appendix A: Statistical Notes – CII Dataset 57
Appendix B: Metric Definitions 59
Appendix C: Project Phase Definitions – CII Dataset 63
Appendix D: Calculation of A/I Technology and Other Indices 65
Appendix E: Quartile Analyses for Mapping Indices 73
Appendix F: Statistical Correlations between the A/I Tech and IT Indices and Performance 99
Appendix G: References 109

List of Tables

Table 2-1. Structure of NIST Survey Instruments 7
Table 2-2. Interoperability Report Survey Instruments Business Management Functions 8
Table 2-3. Business Process Management System Function – Job Classifications............ 9
Table 2-4. Work Functions for Automation/Integration Technology in CII 11
Table 2-5. Southeastern U.S. Contractors Work Functions.. 12
Table 2-6. Relation between NIST Business functions and CII Work Functions 15
Table 2-7. Mapping of Interoperability Report Business Process Management Functions and Southeastern U.S. Contractors Work Functions 19
Table 3-1. Summary of Mean Performance Outcomes – CII Owners............................. 25
Table 3-2. Summary of Mean Performance Outcomes – CII Contractors 28
Table 3-3 Task/Work Functions and Response Scales... 31
Table 3-4. Summary of A/I Tech Practice Use – CII Owners.. 33
Table 3-5. Summary of A Tech Practice Use – CII Owners 34
Table 3-6. Summary of I Tech Practice Use – CII Owners.. 34
Table 3-7. Summary of A/I Tech Practice Use – CII Contractors.................................... 35
Table 3-8. Summary of A Tech Practice Use – CII Contractors 36
Table 3-9. Summary of I Tech Practice Use – CII Contractors.. 36
Table 3-10. Summary of Mean Performance Outcomes – Southeastern U.S. Contractors Dataset... 39
Table 3-11 Sample Work Functions and Response Scales... 39
Table 3-12. Summary of IT Index Scores... 40
Table 3-13. Survey Instrument Comparison... 41
Table 4-1. Correlation of A/I Tech Use with Project Outcomes – CII Owners................ 45
Table 4-2 Correlation of A Tech Use with Project Outcomes – CII Owners................... 46
Table 4-3 Correlation of I Tech Use with Project Outcomes – CII Owners..................... 47
Table 4-4 Correlation of A/I Tech Use with Project Outcomes – CII Contractors 49
Table 4-5 Correlation of A Tech Use with Project Outcomes – CII Contractors............. 50
Table 4.6 Correlation of I Tech Use with Project Outcomes – CII Contractors............... 51
Table 4-7. Correlation of IT Index Use with Company Performance 53

List of Figures

Figure 2-1. Representation of Estimation Approach of Interoperability Report 4
Figure 2-2. Procedure and Data Sources for Interoperability Report Cost Calculation 5
Figure 2-3. CII Benchmarking Process.. 10
Figure 3-1. CII Data Set by Respondent Type and Location... 21
Figure 3-2. CII Data Set by Industry Group 22
Figure 3-3. CII Data Set by Cost of Project... 22
Figure 3-4. CII Data Set by Project Nature.. 23
Figure 3-5. Southeastern U.S. Contractors Dataset by Industry Sectors 37
Figure 3-6. Southeastern U.S. Contractors Dataset by Revenue 38

List of Abbreviations

3D	Three Dimensional
A&E	Architects and Engineers
A/I Tech	Automation and Integration Technologies
A Tech	Automation Technologies
CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
CAx	Computer-Aided System
CII	Construction Industry Institute
C.T.	Confidentiality Test
DART	Days Away, Restricted, or Transfer case incidence rate
D/IT	Design Information Technology
EDI	Electronic Data Interchange
EMR	Experience Modification Rate
GC	General Contractors
IT	Information Technology
I Tech	Integration Technologies
NIST	National Institute of Standards and Technology
O&M	Operations and Maintenance
OO	Owners and Operators
RFI	Requests For Information
SF	Specialty Fabricators and Suppliers
TRIR	Total Recordable Incidence Rate

1. INTRODUCTION

1.1 Background

In 2004, the National Institute of Standards and Technology (NIST) published GCR 04-867 estimating the efficiency losses in the U.S. capital facilities industry resulting from inadequate interoperability. The estimated cost to all stakeholders is $15.8 billion per year. Partial impetus for the interoperability cost study stemmed from two earlier NIST studies conducted by the Construction Industry Institute. These studies, GCR 99-786 and GCR 01-821, found that cost and schedule performance improves with increased use of information technologies (IT). While compelling, these earlier studies focused on specific technologies and do not capture the benefits (or lack thereof) of IT use across a range of business functions. These studies are also dated given the rapidly evolving use of IT within the capital facilities industry. As such, it is useful to reassess the impact of IT on performance across a range of project business or work functions.

CII is a unique consortium of owners, contractors, suppliers, and universities formed to improve the capital project delivery process. Its research agenda and activities are the result of a collaborative effort between industry and academic researchers. Through this ongoing collaboration, CII has established a database that supports the benchmarking of construction industry performance and practice use metrics. The data have been systematically collected since 1996 to support CII benchmarking and research efforts. The database includes over 1 450 projects valued at more than $65 billion from 97 member companies and organizations. In 2002, CII's benchmarking survey was altered to add questions assessing use of automation and integration technologies (A/I Tech) as a measure of IT use. Prior to this a Design and Information Technology (D/I Tech) metric was used to assess the use of four specific technologies.

1.2 Purpose

The purpose of this research was to measure and evaluate the economic value of using information technologies within the construction industry. Specifically, this investigation identified and documented the benefits of using information technologies from actual project and company experiences during the project delivery process.

1.3 Scope and Approach

Two datasets are analyzed in this study. One was developed by CII's Benchmarking & Metrics (BM&M) organization and contains detailed performance measures in addition to the A/I Tech metrics. The CII data were reported by owner and contractors for U.S. domestic and international projects between 2002 and 2004. To better ensure that owner and contractor data were comparable in scope, only those projects for which contractors performed both design and construction tasks were included. The final CII dataset included data from 139 projects, 94 from owners and 45 from contractors. The other complementary data set was independently developed under the direction of Dr. William

O'Brien, a faculty member at the University of Texas at Austin. Dr. O'Brien's dataset consists of company level data from 74 contractors in the Southeastern United States and were collected in 2003 while Dr. O'Brien was a faculty member at the University of Florida.

This research consists of four tasks. The first task is mapping business process management functions from the previous NIST sponsored research (GCR 04-867) and CII BM&M A/I Tech task work functions. In the NIST study, a significant portion of the estimated interoperability cost occurs later in the facility life cycle and is attributed to inefficiencies in these business process management functions attributed to a lack of interoperability. While CII task work functions are performed earlier during the project delivery process, they still assess management processes and relating both sets of functions affords a potential opportunity to corroborate findings in the original NIST study with data from the CII dataset. A similar mapping exercise was performed between the GCR 04-867 business process management functions and the O'Brien dataset (hereafter called Southeastern U.S. Contractors dataset). All mappings are presented and discussed in Chapter 2.

The second task describes the contents of the two data sets, including performance measures and CII's A/I Tech metrics and the Southeastern U.S. Contractors IT usage measures. Beyond basic descriptive statistics, this task developed baseline measures of performance and indicators of economic value. For the CII data, industry norms were identified on five key outcomes: cost, schedule, safety, changes, and field rework. For the Southeastern U.S. Contractors dataset, five key outcomes of cost, schedule, safety, profit, and customer satisfaction are detailed. IT usage norms are based on CII's A/I Tech index and the Southeastern U.S. Contractors IT index.

The third task correlates degree of IT use with the various performance measures in each database. For the CII data, IT usage is reported for both automation and integration technologies. Since it is possible that the levels of automation and integration technologies use are different, data analyses with only automation technologies (A Tech) and only integration technologies (I Tech) are performed in addition to a combined A/I Tech index. The Southeastern U.S. Contractors dataset contains more detailed work functions than the CII dataset; however, the assessment of IT use is not segregated into automation and integration. Correlations are presented by quartile analysis in Chapter 4 and statistical analysis of correlations is included in the appendices. Additional A/I Tech indices and correlations were developed based on the mapping work of task one; these analyses are presented in Chapter 4 as well as in the appendices.

The final task of this research was the development of this report, which summarizes and synthesizes the findings from Tasks 1, 2, and 3. Baseline measures of performance are discussed and key measures of economic value are identified.

2. SUMMARY OF TASK 1 - MAPPING

This chapter summarizes the data and methodological approaches of the NIST GCR 04-867 Cost of Inadequate Interoperability in the U.S. Capital Facilities Industry report (Interoperability Report) and the CII BM&M questionnaire concerning use of automation and integration technologies (A/I Tech). In addition, specific mappings are made between Interoperability Report business process management functions and CII A/I Tech task work functions. Mapping between the Interoperability Report functions and the work functions used for the Southeastern U.S. Contractors study are also presented. Although the Interoperability Report and the CII and Southeastern U.S. Contractors datasets vary in approach to data collection and analysis, mapping allows reasonable comparison between findings of IT use and performance.

This chapter consists of four parts. The first summarizes the methodology of the Interoperability Report study and presents the business process management functions used therein. The second presents the CII A/I Tech task work functions and the third describes the IT utilization work functions in the Southeastern U.S. Contractors dataset. The fourth presents mappings between the Interoperability Report business process management functions and the work functions in the CII and Southeastern U.S. Contractors datasets.

2.1 Interoperability Report: Methodology and Business Process Management Functions

The report published by NIST in 2004 (NIST GCR 04-067) estimates $15.8 billion cost due to poor interoperability were incurred by the U.S. capital facilities industry in 2002. The interoperability costs were estimated using a work process model, estimates of various costs, and total square meters constructed and in service. It should be noted that of the $15.8 billion, $6 billion were attributed to inefficient business process management functions relating to the cost of design and construction activities, which are the measured by the CII and Southeastern U.S. Contractors datasets.

2.1.1 Definition of Inadequate Interoperability Costs

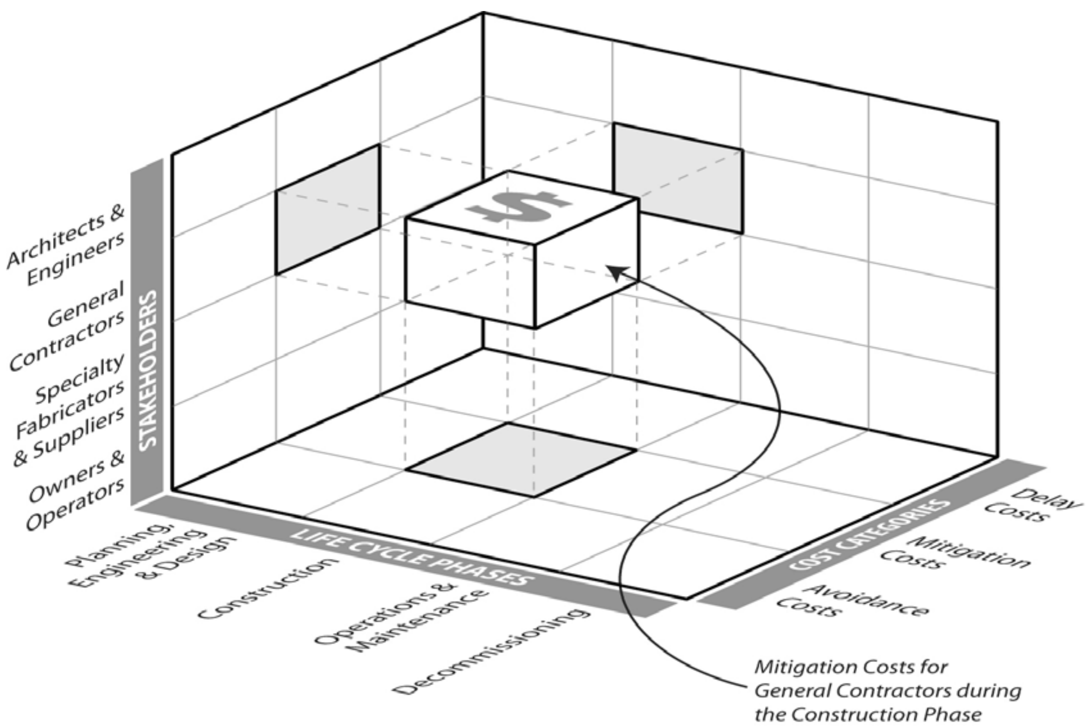
In the Interoperability Report, the cost of inadequate interoperability is quantified by comparing current business activities and costs with a hypothetical counterfactual scenario in which electronic data exchange, management, and access are fluid and seamless. The difference between the current and counterfactual scenarios represents the total economic loss associated with inadequate interoperability. For the cost quantification, the inadequate interoperability cost was divided into three categories as follows:
A. Avoidance Costs: Avoidance costs are related to the ex-ante activities stakeholders undertake to prevent or minimize the impact of technical interoperability problems before they occur.

B. Mitigation Costs: Mitigation costs stem from ex-post activities responding to interoperability problems. Most mitigation costs result from electronic or paper files that had to be reentered manually into multiple systems and from searching paper archives. Mitigation costs in this analysis may also stem from redundant construction activities, including scrapped materials costs.
C. Delay Costs: Delay costs arise from interoperability problems that delay the completion of a project or the length of time a facility is not in normal operation.

2.1.2 Calculation of the Inadequate Interoperability Cost

To quantify the cost due to inadequate interoperability, survey instruments were developed for owners and operators (OO), general contractors (GC), specialty fabricators and suppliers (SF), and architects and engineers (A&E). Based on the surveys, costs were categorized according to facility life cycle which includes design and engineering, construction, operations & maintenance (O&M), and decommissioning. Inadequate interoperability costs are categorized in a 3-D framework as shown in Figure 2-1.

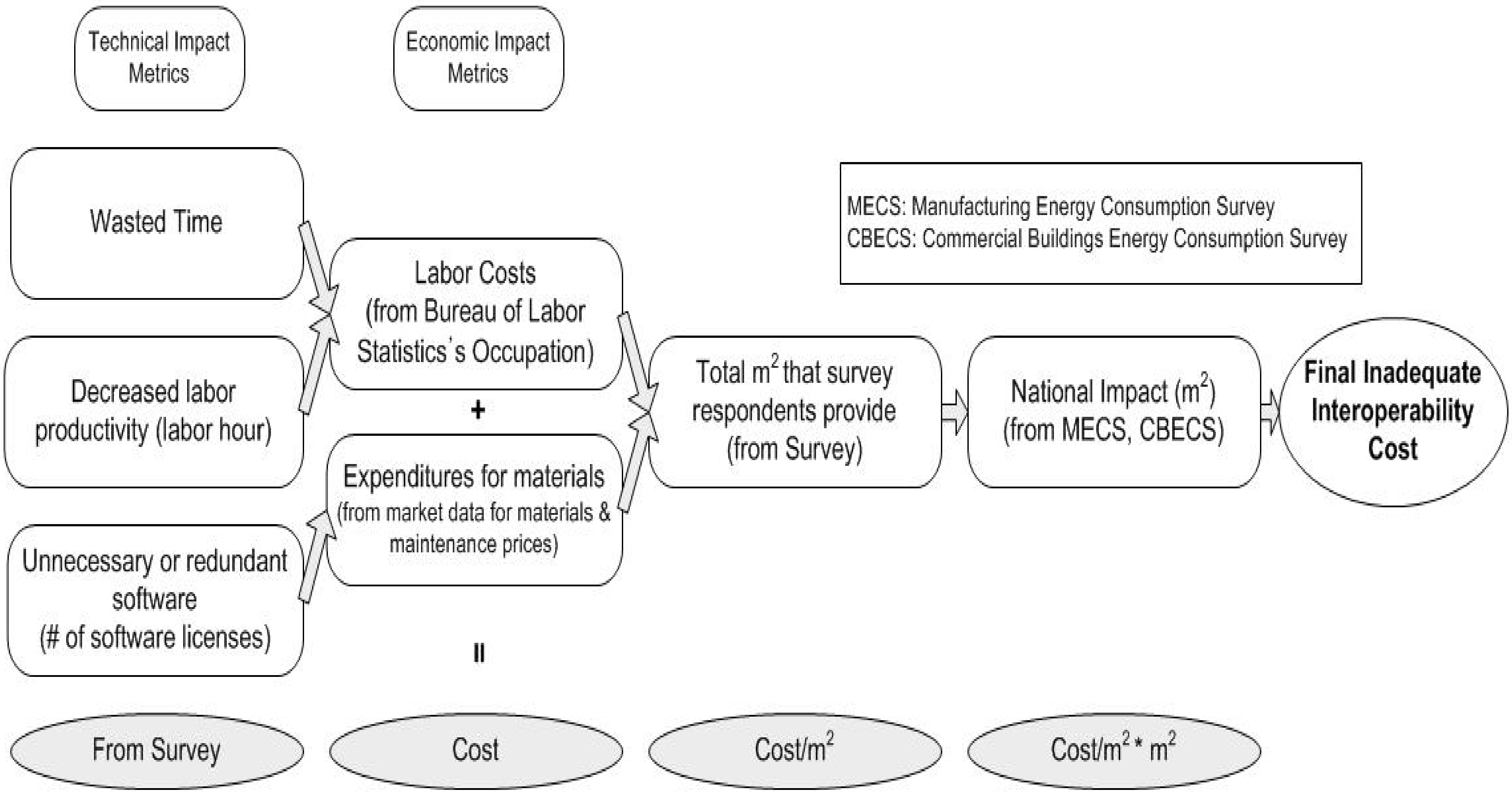
Figure 2-1. Representation of Estimation Approach of Interoperability Report



Source: NIST GCR 04-867 page 4-7

Figure 2-2 shows the calculation procedure for determining interoperability costs. Data for technical impact metrics such as wasted time, productivity loss due to inadequate interoperability and unnecessary software systems were obtained through survey instruments. These data were transformed to costs according to economic impact metrics, and then transformed to a cost per square meter (m^2) of facility. National measures of capital facility stock in the U.S. were used to scale the costs to a summary metric.

Figure 2-2. Procedure and Data Sources for Interoperability Report Cost Calculation



2.1.3 Interoperability Report Survey Instruments

In the Interoperability Report, survey instruments were developed for each stakeholder including owners and operators (OO), general contractors (GC), specialty fabricators and suppliers (SF), and architects and engineers (A&E). Table 2-1 summarizes the structure of each survey instrument; there were slight differences based on respondent class, but the basic structure is the same. The OO survey differed the most from the other classes as it surveyed existing facility stock for operations and maintenance costs while other classes focused on design and construction activities. As shown in the table, all types of surveys consist of seven parts. The first two parts contain general information about respondents and their capacity which is needed to calculate the national impact of inadequate interoperability costs. The last five parts cover IT systems and supports, interoperability problems, delay costs, business process systems, and operation and maintenance costs. Questions developed for IT systems and support include existence of redundant IT software, costs for purchasing, educating, and maintaining the software. Questions for interoperability problems cover information reentry caused by use of multiple IT systems (two electronic software or one electronic software and paper-based system). Problems related to requests for information (RFI) are also considered in this part. Delay costs originate from any interoperability costs due to any type of delay. The sixth part of the survey contains the business process management system functions that mapped with CII task work functions in the next part of this report. The last section, "operations and maintenance phases," is only for OO surveys for facilities management software system and staff.

Table 2-1. Structure of NIST Survey Instruments

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">Topic</th><th colspan="4">Contents</th></tr>
<tr><th>OO</th><th>GC</th><th>SF</th><th>A&E</th></tr>
<tr><td>1</td><td>Respondent Identification</td><td colspan="4">General information</td></tr>
<tr><td>2</td><td>Capacity</td><td>Capital facilities stock under construction & management</td><td colspan="3">Annual activities</td></tr>
<tr><td>3</td><td>IT Systems & Supports</td><td rowspan="2">In design & construction life-cycle phase:
- CAD/CAM/CAE (CAx) systems
- Interoperability problems (reentry, RFI)</td><td colspan="3">CAD/CAM/CAE (CAx) systems, data translation systems & interoperability research</td></tr>
<tr><td>4</td><td>Interoperability Problems</td><td>Before, during, and after construction (reentry and RFI)</td><td colspan="2">Before and after construction (reentry and RFI)</td></tr>
<tr><td>5</td><td>Delay Costs</td><td colspan="4">Interoperability cost due to any types of delay</td></tr>
<tr><td>6</td><td>Business Process Systems</td><td>14 functions</td><td colspan="2">14 functions</td><td>10 functions</td></tr>
<tr><td>7</td><td>Operation & Maintenance Phases</td><td>Facilities management software system and staff</td><td colspan="3">N/A</td></tr>
</table>

2.1.4 Business Process Management Functions

Business process management functions are a part of the Interoperability Report survey instruments and provide classes for the quantification of inadequate interoperability costs. There are fourteen business process management functions. Surveys for OO, GC, and SF contained all functions; whereas surveys developed for A&E contain only 10 functions. Each function represents one business process system. For each function, information obtained from the respondents includes existence of software for a specific business process, approximate number of full-time equivalent employees for the system, and percentage labor reduction that can be achieved if the process is fully electronic and interoperable. Table 2-2 shows the functions and stakeholder groups affected by the function. All costs involved with business process management functions are included in avoidance costs.

Table 2-2. Interoperability Report Survey Instruments Business Management Functions

No.	Business Process Management Functions	Impact of Inadequate Interoperability to
A	Accounting	A&E, GC, SF, OO
B	Cost Estimation	A&E, GC, SF, OO
C	Document Management	A&E, GC, SF, OO
D	Enterprise Resource Planning	A&E, GC, SF, OO
E	Facility Planning and Scheduling	A&E, GC, SF, OO
F	Facility Simulation	A&E, GC, SF, OO
G	Information Request Processing	A&E, GC, SF, OO
H	Inspection and Certification	GC, SF, OO
I	Maintenance Planning and Management	GC, SF, OO
J	Materials Management	A&E, GC, SF, OO
K	Procurement	A&E, GC, SF, OO
L	Product Data Management	GC, SF, OO
M	Project Management	A&E, GC, SF, OO
N	Start-up and Commissioning	GC, SF, OO

The Interoperability Report provides limited definitions of each of these functions. Some clarification can be found by matching the job type to the functions as described in Table 2-3 below.

Table 2-3. Business Process Management System Function – Job Classifications

	A&E		*GC*	*SF*	*OO*
	Architects	***Engineers***			
Accounting	Accountants and Auditors				
Cost Estimation	Cost Estimators				
Document Management	Executive Secretaries and Administrative Assistants				
Enterprise Resource Planning	Management Analysts				
Facility Planning and Scheduling	Civil Engineers				
Facility Simulation	Civil Engineers				
Information Request Processing	Executive Secretaries and Administrative Assistants				
Inspection & Certification	N/A		Civil Engineers		
Maintenance Planning and Management	N/A		Civil Engineers		
Materials Management	Production, Planning, and Expediting Clerks				
Procurement	Purchasing Agents, Except Wholesale, Retail, and Farm Products				
Product Data Management	N/A		Management Analysts		
Project Management	Architects, Except Landscape and Naval	Civil Engineer	Construction Manager		
Start-up & Commissioning	N/A		Civil Engineers		

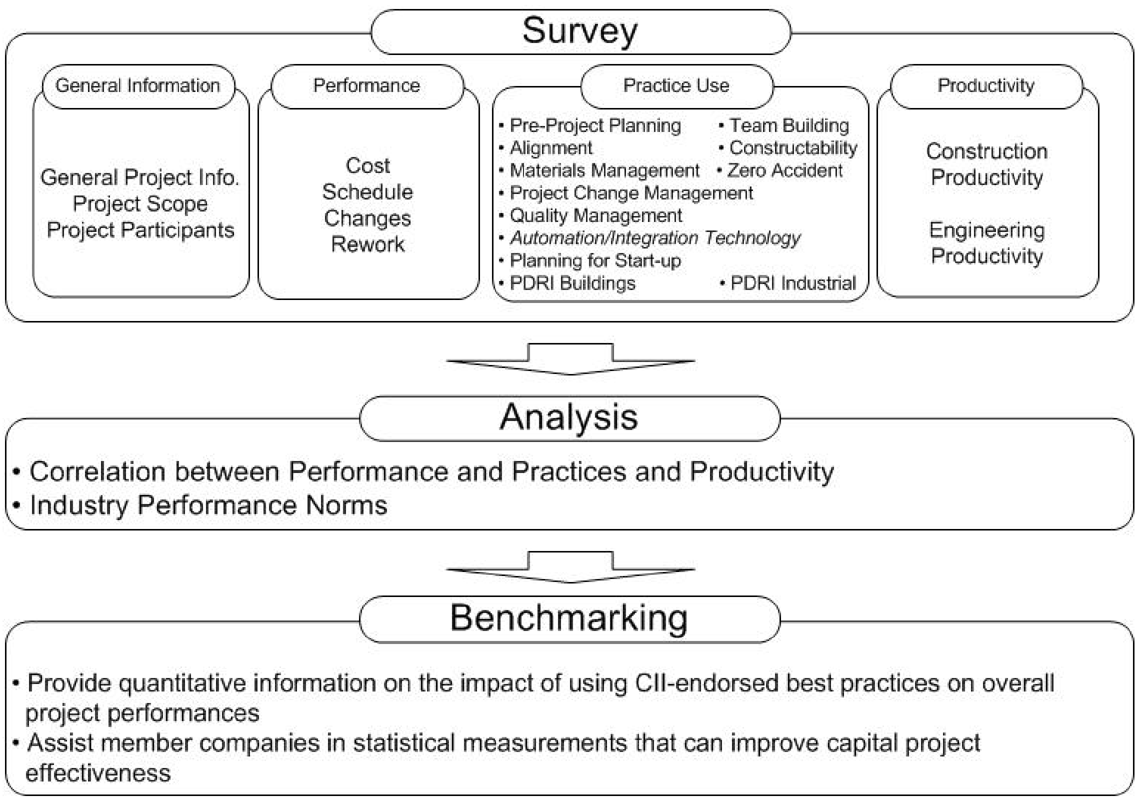
(NIST GCR 04-867, Appendix C)

2.2 CII A/I Tech Task Work Functions

2.2.1 CII Benchmarking & Metrics Program

The CII Benchmarking & Metrics (BM&M) Program was established to provide industry performance norms and to quantify the level of use and value of CII best practices. The goals of the BM&M Program include providing quantitative information to member companies on project performance impacts attributed to using CII best practices as well as assisting member companies with statistical measurements that can improve capital project effectiveness. Figure 2-3 illustrates the process of the CII BM&M Program.

Figure 2-3. CII Benchmarking Process



2.2.2 A/I Tech Task Work Functions

A/I Tech task work functions are project management functions used to assess the level of technology use of automation and integration in the CII survey instrument as shown in Figure 2-3. The CII survey assesses the degree of automation and then integration between each work function. There are a total of 13 functions since the “project management” function is sub-divided into five functions. Task work functions are scored by respondents for both automation and integration. Seven options are available for response. Levels 1 through 5 indicate levels of use and integration with Level 1 indicating little or no automation and integration. Level 5 indicates full automation of functions and full integration of technologies among these functions. Levels 2, 3, and 4 are scaled between levels 1 and 5. “Not applicable” and “unknown” are also options that respondents can select. Table 2-4 shows all 13 CII task work functions used to assess both automation and integration of technology.

Table 2-4. Work Functions for Automation/Integration Technology in CII

<table>
<tr><th colspan="2">No.</th><th>CII Work Functions</th></tr>
<tr><td colspan="2">1</td><td>Business Planning & Analysis</td></tr>
<tr><td colspan="2">2</td><td>Conceptual Definition & Design</td></tr>
<tr><td colspan="2">3</td><td>Project (Discipline) Definition & Facility Design</td></tr>
<tr><td colspan="2">4</td><td>Supply Management</td></tr>
<tr><td rowspan="5">5
Project
Management</td><td>5-1</td><td>Coordination System</td></tr>
<tr><td>5-2</td><td>Communications System</td></tr>
<tr><td>5-3</td><td>Cost System</td></tr>
<tr><td>5-4</td><td>Schedule System</td></tr>
<tr><td>5-5</td><td>Quality System</td></tr>
<tr><td colspan="2">6</td><td>Off-Site / Pre-Construction</td></tr>
<tr><td colspan="2">7</td><td>Construction</td></tr>
<tr><td colspan="2">8</td><td>As-Built Documentation</td></tr>
<tr><td colspan="2">9</td><td>Facility Start-Up & Life Cycle Support</td></tr>
</table>

2.3 Work Functions Used for the Southeastern U.S. Contractor Dataset

Independent of CII, in 2003 Dr. O’Brien and a Ph.D. student, Mohammad El-Mashaleh, directed a study relating project performance to IT use at the company level (El-Mashaleh, 2003 and El-Mashaleh et al., 2006). Data from 74 contractors in the Southeastern United States were collected by survey. Each respondent was also surveyed for information technology use in four categories: procurement, construction management, construction execution, and start-up. Each category contains multiple work functions. Table 2-5 lists the four categories and 48 work functions used for this study. For each work function which measures the use of IT for that specific function, respondents have five options as responses: three options for indicating the degree of IT use, one option for “don’t know” and one option for “not available.” Based on the responses, an index of IT use was developed to measure the overall IT level of use for the company. Company level performance data were also obtained on five metrics relating to cost, schedule, profit, safety, and customer satisfaction (see definitions in Appendix B, Section B.2).

Table 2-5. Southeastern U.S. Contractors Work Functions

Phase	***No.***	***Work Function***
Procurement	1	Determine the lead time required to order equipment and materials
	2	Conduct a quantity survey of drawings
	3	Link quantity survey data to the cost estimating process
	4	Link supplier cost quotes to the cost estimating process
	5	Refine the preliminary budget estimate
	6	Develop the milestone schedule
	7	Develop and transmit requests for proposal to suppliers and subs
	8	Prepare and submit shop drawings
	9	Acquire and review shop drawings; send response
	10	Compile quotes from suppliers and subs into a bid or proposal package
	11	Monitor the progress of fabricators
	12	Plan the transportation routes of large items from the fabricator to the job site
Construction Management	13	Develop the construction schedule
	14	Track field work progress and labor cost code charges
	15	Maintain a daily job diary
	16	Update the current cost forecast
	17	Keep all project team members up to data on construction progress
	18	Track the inventory of materials on site
	19	Link field material managers to suppliers
	20	Develop short-term work schedules based on labor, equipment, and material availability
	21	Work crews submit and receive answers to Requests for Information
	22	Builders provide feedback about the effects of design changes, made by owners or A/E, on cost and schedule
	23	Communicate design changes to field personnel
	24	Communicate status of change orders to field
	25	Update as-built drawings
	26	Contractors submit requests for payment
	27	Transfer funds from owner's account to contractor
Construction Execution	28	Evaluate subsurface conditions
	29	Carry out earth work and grading
	30	Construct rebar charges
	31	Weld pipes
	32	Select the appropriate crane for heavy lifts
	33	Provide an elevated work platform
	34	Fabricate roof trusses
	35	Manipulate and hang sheet rock
	36	Acquire and record laboratory test information
	37	Finish concrete surfaces
	38	Apply paint or coatings
Maintenance and Start-up	39	Conduct pre-operations testing
	40	Train facility operators (e.g. simulation, software)
	41	Use as-built information in personnel training
	42	Track and analyze the maintenance history of important equipment
	43	Develop maintenance plans from maintenance history data
	44	Monitor & assess equipment operators
	45	Facility operators request maintenance or modifications
	46	Update as-built drawings in response to facility modifications
	47	Monitor/track/control facility energy usage
	48	Monitor environmental impact of facility operations (e.g. air/water/quality)

A review of the CII task work functions in Table 2-4 and the Southeastern U.S. Contractors work functions in Table 2-5 reveals very different levels of definition. CII functions are generally defined at a very high level of project planning and execution, whereas, the functions from the Southeastern U.S. Contractors dataset are defined at much lower levels within project management and execution phases. These different levels of definition appear to affect the respondents' ability to assess the level of IT use for that function as will be shown in Chapter 3.

The NIST Interoperability Report business process management functions in Table 2-2 were identified as capital facility industry functions impacted by inadequate interoperability. These functions are defined at a higher level similar to the CII functions. In some cases CII functions are defined at an even higher level such as "Business Planning and Analysis" or "Conceptual Planning & Design" versus the Interoperability Report functions of "Facility Planning and Scheduling." In other cases such as the Interoperability Report function of "Project Management," CII divides this function into five separate project management systems of "Coordination System," Communication System," "Cost System," "Schedule System," and "Quality System." Both sets of functions have considerable overlap suggesting an opportunity for mapping one to the other.

2.4 Mapping

2.4.1 Mapping of the Interoperability Report Business Process Management Work Functions and the CII A/I Tech Work Functions

This section describes the mapping process between the Interoperability Report business process management work functions and the CII A/I Tech task work functions. Both the NIST Interoperability Report and the CII A/I Tech metrics provide insight into the level of interoperability in the US capital facilities industry. However, there are substantial differences in methodology. As described above, the Interoperability Report focuses on estimating the cost of inadequate interoperability via specific time and cost metrics for each responding firm. These metrics are then scaled by the size of the national capital facilities stock. In contrast, CII's A/I Tech metrics simply assess the level of automation of the particular function and integration across all functions which can be correlated with performance metrics such as cost, schedule, and safety. While CII A/I Tech metrics support the cost and schedule benefits of automation and integration during project delivery, mappings can be made between the NIST Interoperability Report business process management functions and CII A/I Tech task work functions to narrow the analysis and focus our understanding of the benefits and costs of automation and integration technologies on capital project delivery.

2.4.2 Mapping Detail

Mapping the Interoperability Report business process management functions and the CII A/I Tech functions was performed as a group exercise by Drs. Thomas and O'Brien, CII post doctoral researcher Dr. L. Liang, and Ph.D. graduate research assistant Y. Kang. Three levels of association were selected for the mapping: closely related, somewhat related, and not related. Table 2-6 documents the mapping, showing assessment of association for closely related and somewhat related functions. Note that each CII A/I Tech task work function may be mapped to more than one Interoperability Report business process management function and also that multiple A/I Tech work functions may map to a single business process management function. While CII collects data for automation and integration separately, the research team did not determine any case where the metrics have separate mappings. Hence Table 2-6 reports just one mapping for both automation and integration metrics.

Table 2-6. Relation between NIST Business functions and CII Work Functions

NIST Business Process Management Functions		Mapped CII Work Functions	
No.	**Business Functions**	**Closely related**	**Somewhat related**
A	**Accounting**		1, 5-3
B	**Cost Estimation**	2, 5-3	1
C	**Document Management**	5-1, 5-2, 8	5-5, 7
D	**Enterprise Resource Planning**		1
E	**Facility Planning and Scheduling**	5-4	2, 3, 5-3, 6
F	**Facility Simulation**		1
G	**Information Request Processing**	5-1, 5-2	
H	**Inspection and Certification**	5-5	6, 7, 9
I	**Maintenance Planning and Management**	9	
J	**Materials Management**	4	6
K	**Procurement**	3, 4, 5-3, 5-4, 6	
L	**Product Data Management**	5-1, 5-2, 7, 8	4, 5-3, 5-4, 5-5
M	**Project Management**	5-3, 5-4, 5-5, 7	4, 6, 8, 5-1, 5-2
N	**Start-up and Commissioning**	9	5-4, 5-5, 8

CII Work Functions
1. Business Planning & Analysis
2. Conceptual Definition & Design
3. Project Definition & Facility Design
4. Supply Management
5. Project Management
5-1. Coordination System
5-2. Communication System
5-3. Cost System
5-4. Schedule System
5-5. Quality System
6. Off-Site / Pre-Construction
7. Construction
8. As-Built Documentation
9. Facility Start-Up & Life Cycle Support

While Table 2-6 summaries the mappings, the following text provides a brief discussion about the mappings between the Business Process Functions (designated by their letter and name in Table 2-6) and A/I Technology work functions (designated by their number and name placed within quotation marks). In most cases the mappings are self explanatory, but additional discussion is provided where appropriate.

A. Accounting

The Accounting function was too specific compared with CII work functions making it difficult to find any CII functions that map closely. However, Accounting would be included in the "5-3 Cost System" and likely in "1 Business Planning & Analysis" producing somewhat related mappings.

B. Cost Estimation

Several CII work functions map to Cost Estimation. Both "2 Conceptual Definition & Design" and "5-3 Cost System" are closely related to Cost Estimation and "1 Business Planning & Analysis" is also related, but to a lesser degree. Cost estimates are routinely required when a project is in "2 Conceptual Definition & Design" and "1 Business Planning & Analysis" require early cost estimates to support economic analyses.

C. Document Management

A number of CII work functions map to the Document Management function. "5-1 Coordination" and "5-2 Communication Systems" depend on documentation and "8 As-Built Documentation" clearly requires good document management producing closely related assessments. The "5-5 Quality System" requires documentation management too and "7 Construction" cannot be performed without documentation management. Although the mapping team identified only these two functions as somewhat related, clearly most CII functions have to have some degree document management.

D. Enterprise Resource Planning

There is no specific CII work function which can be directly linked to Enterprise Resource Planning; however, "1 Business Planning & Analysis" was thought to have some connection producing a somewhat related assessment.

E. Facility Planning and Scheduling

Given the high level of definition of CII work functions, it is not surprising that a number of these functions map to Facility Planning and Scheduling. "5-4 Schedule System" is closely related. "2 Conceptual Definition & Design," "3 Project Definition & Facility Design," "5-3 Cost System," and "6 Off-Site / Pre-Construction" were thought to be at least somewhat related.

F. Facility Simulation

No CII function was assessed as closely related to the Facility Simulation function. However, since facility simulation is often used during "2 Conceptual Definition & Design," this CII function was rated as somewhat related.

G. Information Request Processing

This function proved somewhat problematic for mapping since many of the CII functions require processing of information, but do not necessarily process information requests. "5-1 Coordination" and "5-2 Communication Systems" are essential for Information Request Processing and were therefore assessed as closely related.

H. Inspection and Certification

"5-5 Quality System" clearly links to Inspection and Certification warranting a closely related rating and "6 Off-Site and Pre-Construction," "7 Construction," and "9 Facility Start-up & Life Cycle Support" were deemed to be somewhat related.

I. Maintenance Planning and Management

This business process function received one closely related CII function map, "9 Facility Start-Up & Life Cycle Support." While a number of other CII functions were discussed, none of these functions were mapped even at the somewhat related level.

J. Materials Management

The CII function "4 Supply Management" directly relates to this business process management function and is assessed as closely related. "6 Off-Site and Pre-Construction" requires good materials management and also received an assessment, but at the somewhat related level.

K. Procurement

This business process work function received several CII function mappings which are expected given the early life cycle nature of many of the CII functions. Procurement commences following definition and authorization and continues up to start-up and commissioning. "3 Project Definition & Facility Design," "4 Supply Management," "5-3 Cost System," "5-4 Schedule System," and "6 Off-Site / Pre-Construction" all mapped as closely related.

L. Product Data Management

Data management is very broad concept and as would be expected, many CII functions mapped well with it. All CII functions within "5 Project Management" mapped to some degree with "5-1 Coordination System" and "5-2 Cost System" mapping as closely related. The other Project Management functions as well as "4 Supply Management" mapped as somewhat related. Two other CII functions: "7 Construction" and "8 As-built Documentation" also mapped closely related since they rely heavily on data management.

M. Project Management

As would be expected given the level of definition of CII functions, the business process management function Project Management received the largest number of CII function mappings. All CII "5 Project Management" functions mapped with "5-3 Cost System," "5-4 Schedule System," and "5-5 Quality System" mapping as closely related and "5-1 Coordination System" and "5-2 Communication System" mapping as somewhat related. The latter two CII project management functions are less understood, likely contributing to their weaker mappings. Other CII functions mapped include "7 Construction" as closely related and "4 Supply Management," "6 Off-Site / Pre-Construction," and "8 As-built Documentation" mapping as somewhat related.

N. Start-up and Commissioning

As would be expected this function mapped closely related with the CII function "9 Facility Start-up & Life Cycle Support." Other CII functions that mapped somewhat related include "5-4 Schedule System," "5-5 Quality System," and "8 As-built Documentation." It is possible to argue that these "somewhat related" CII metrics could be classified as closely related.

2.4.3 Mapping of Interoperability Report Business Process System Functions and Southeastern U.S. Contractors Work Functions

The dataset developed from contractors in the Southeastern U.S. is similar in structure to the CII dataset, containing both performance measures and work function assessments of IT use. The IT work functions used in this dataset are grouped into four categories, two of which map directly to the Interoperability Report business process management functions. These function categories are Procurement and Construction Management. As shown in Table 2-5, 12 work functions are categorized in the Procurement group and each of these work functions can be mapped as closely related to the Interoperability Report Procurement business process function as shown in Table 2-7.

For the Interoperability Report Project Management function, two mappings are provided. The first directly maps all the Southeastern U.S. Contractors Construction Management work functions (numbers 13 through 27) into the Project Management I grouping. The second mapping examines individual Southeastern U.S. Contractors Construction Management work functions excluding some from the Construction Management grouping and including a few from the Construction Execution grouping. The reasoning behind the second grouping is that the Interoperability Report Project Management function may be focused on integration technologies, therefore the second Project Management mapping focuses on work functions that are closely related to integration. Table 2-7 lists these mappings as Project Management II.

Table 2-7. Mapping of Interoperability Report Business Process Management Functions and Southeastern U.S. Contractors Work Functions

NIST Business Functions		Work functions from the contractor firm database	
		No.[1]	Task
Procurement		1	Determine the lead time required to order equipment and materials
		2	Conduct a quantity survey of drawings
		3	Link quantity survey data to the cost estimating process
		4	Link supplier cost quotes to the cost estimating process
		5	Refine the preliminary budget estimate
		6	Develop the milestone schedule
		7	Develop and transmit requests for proposal to suppliers and subs
		8	Prepare and submit shop drawings
		9	Acquire and review shop drawings; send response
		10	Compile quotes from suppliers and subs into a bid or proposal package
		11	Monitor the progress of fabricators
		12	Plan the transportation routes of large items from the fabricator to the job site
Project Management	I	13	Develop the construction schedule
		14	Track field work progress and labor cost code charges
		15	Maintain a daily job diary
		16	Update the current cost forecast
		17	Keep all project team members up to data on construction progress
		18	Track the inventory of materials on site
		19	Link field material managers to suppliers
		20	Develop short-term work schedules based on labor, equipment, and material availability
		21	Work crews submit and receive answers to Requests for Information
		22	Builders provide feedback about the effects of design changes, made by owners or A/E, on cost and schedule
		23	Communicate design changes to field personnel
		24	Communicate status of change orders to field
		25	Update as-built drawings
		26	Contractors submit requests for payment
		27	Transfer funds from owner's account to contractor
	II[2]	14	Track field work progress and labor cost code charges
		15	Maintain a daily job diary
		17	Keep all project team members up to data on construction progress
		18	Track the inventory of materials on site
		19	Link field material managers to suppliers
		20	Develop short-term work schedules based on labor, equipment, and material availability
		21	Work crews submit and receive answers to Requests for Information
		22	Builders provide feedback about the effects of design changes, made by owners or A/E, on cost and schedule
		23	Communicate design changes to field personnel
		24	Communicate status of change orders to field
		25	Update as-built drawings
		28	Evaluate subsurface conditions
		36	Acquire and record laboratory test information

[1] Work function numbers are identical to the numbers in Table 2-5
[2] Mapping focused on integration technology

Observations from the mapping exercise conclude that many of the mappings are very subjective and are dependent on the “group think” that the team developed during the process. While the purpose of the mapping exercise was to relate work functions between the various datasets in an effort to identify potential similarities in findings across the datasets, the practicality of this exercise became questionable. The primary benefit obtained through the mappings was identification of closely and somewhat related CII work functions facilitating development of special “mapped” A/I Tech indices which could be checked for improved correlations with project outcomes. The correlations between A/I Tech and outcomes are discussed in detail in Chapter 4, however, the “mapped” A/I Tech indices correlations were dropped from the analysis since they produced results similar to the broader A/I Tech indices. Although the mapped indices produced slightly more significant correlations for one index, the mappings were actually quite subjective and eliminated nearly half of the A/I Tech work functions from the analysis.

3. SUMMARY OF TASK 2 – DESCRIPTIVE STATISTICS

This chapter provides the descriptive statistics for both CII and the Southeastern U.S. Contractors datasets. The datasets are complementary; the CII dataset contains project information from both contractors and owners that are among the larger firms in the capital facilities industry. The Southeastern U.S. Contractors dataset provides company level data among a range of small and midsize contractors drawn primarily from the Southeastern United States.

3.1 CII Data

3.1.1 Data Description

CII data for Automation/Integration technology are drawn from versions 7 and 8 of the CII Benchmarking and Metrics questionnaire, and represent 139 projects reported over the period 2002-2004. Data are categorized by location (Figure 3-1), industry group (Figure 3-2), cost (Figure 3-3), and project nature (Figure 3-4). Each figure shows the number of projects for both owner and contractor respondents.

Note that in some figures the sample size is smaller than the total number of projects since all respondents do not answer all questions. There are some statistical outliers and confidentiality issues with small samples. As such, certain data are excluded from analysis following the decision rules provided in Appendix A. Hence some of the analyses presented in the following sections do not draw from all 139 projects. Where appropriate in the tables, small samples or data suppression for confidentiality are noted.

Figure 3-1. CII Data Set by Respondent Type and Location

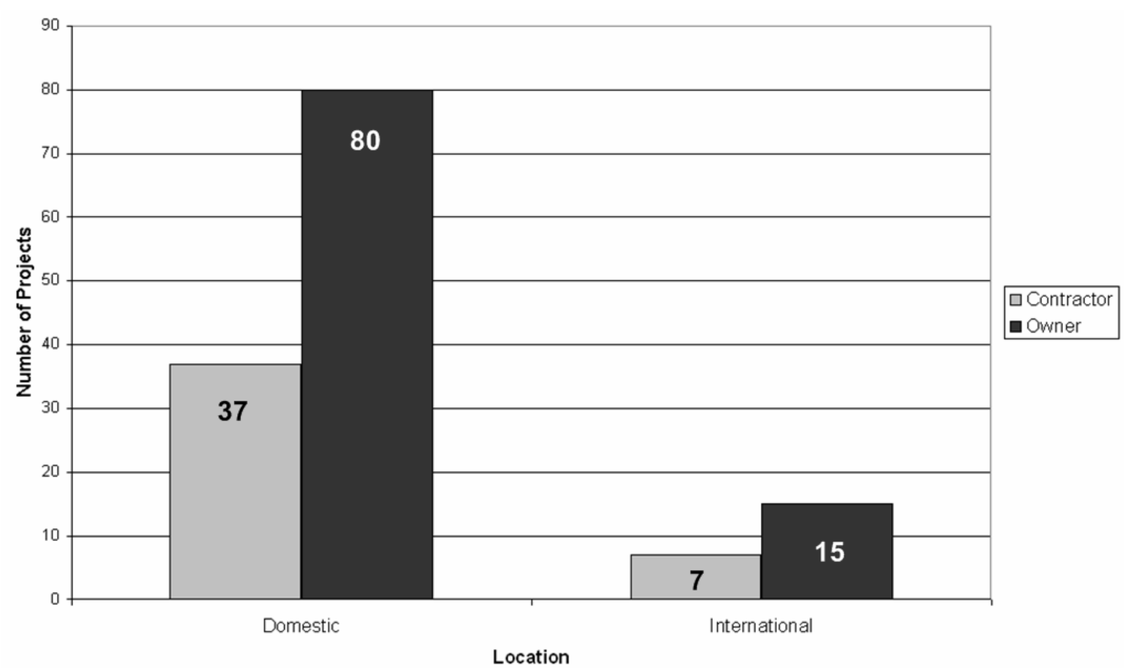


Figure 3-2. CII Data Set by Industry Group

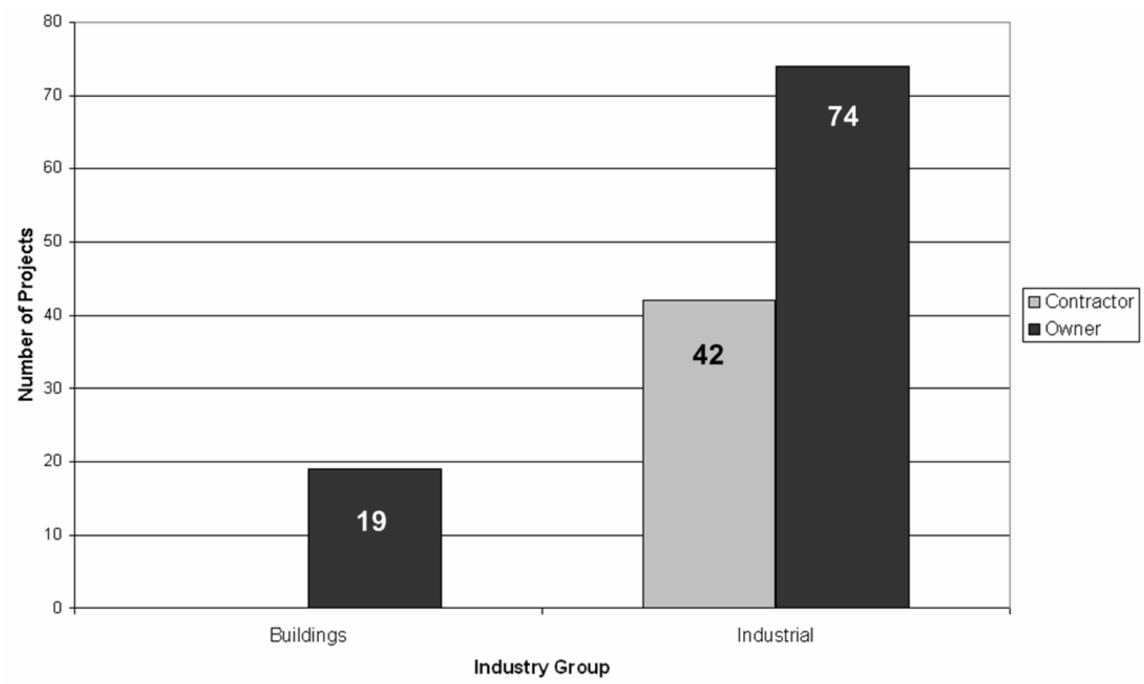


Figure 3-3. CII Data Set by Cost of Project

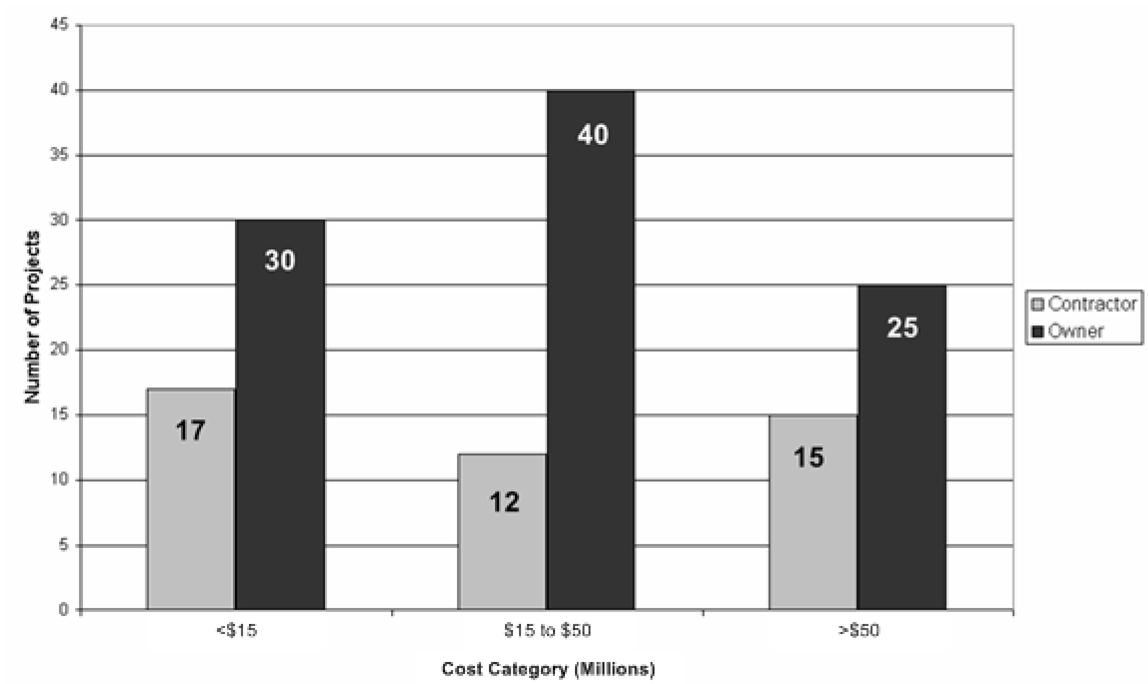
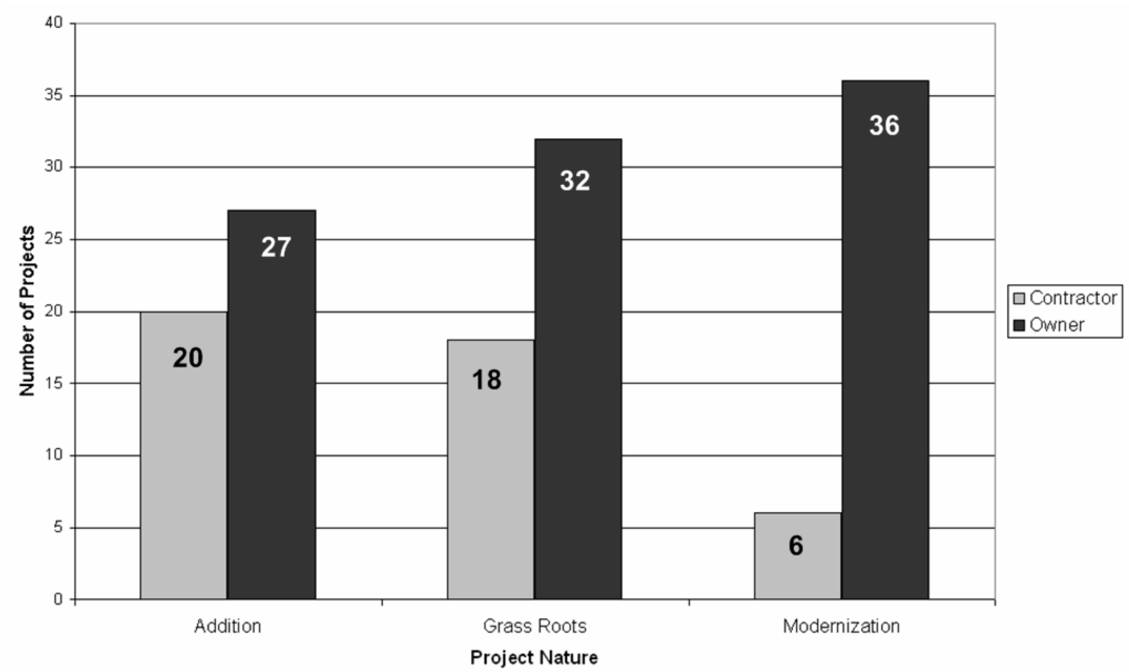


Figure 3-4. CII Data Set by Project Nature



3.1.2 Performance Outcomes – CII Owners

Table 3-1 summarizes owner project performance for each comparison category. The definitions of all metrics are summarized in Appendix B, Section B.1. The shading of cells indicates better performance within the category and values marked with asterisks indicate small samples in accordance with definitions provided in Appendix A. Findings from these small samples should be interpreted with caution. For cases where the data sample is very small (10 or fewer) or the data are provided by less than 3 companies, the data are suppressed and a confidentiality warning indicator (C.T.) is shown. Overall, the owner projects reported very good cost growth of -0.1 %; however, schedule growth at 11.4 % indicates an opportunity for improvement.

Analysis by industry group is limited by the small building sample of only 19 projects. Since some phase data are not reported by all building projects, some data suppression is required. Generally, industrial projects reported better cost and schedule performance than building projects as indicated by lower numbers on the project cost and schedule growth metrics which measure growth from target budgets and schedules. These findings are consistent with most CII benchmarking results which indicate that larger and more complex heavy industrial projects typically report better performance. Alternative project assessment of cost and schedule performance is provided by the "Delta" metrics which measure performance as absolute deviation from targets. By this measure, buildings actually outperformed industrial projects by a slight margin (lower numbers are better for all performance metrics); however, these findings lack statistical significance. Of particular interest is the seemingly better safety performance of the building projects compared to the industrial projects. This observation is not consistent with that of larger datasets of the CII benchmarking database nor findings reported in CII's annual Safety Report which is based on more than one billion work-hours. The small sample for building projects used in this dataset may not be representative of the broader industry.

By cost category, surprisingly, design cost growth was the only performance metric on which larger projects (those costing over $50 million) demonstrated superior performance compared to midsize and smaller projects. This is unusual since CII data routinely show that larger projects tend to employ performance enhancing practices to a greater degree than smaller projects. Overall, midsize projects (costs ranging between $15 million and $50 million) showed the best performance in project cost growth, project budget factor, and project schedule growth. Smaller projects (those costing less than $15 million) showed the best performance for phase level cost and schedule metrics. Smaller projects also were the best in safety performance based on the large percentage of small projects that report no recordable incidents. While the better safety performance of the smaller projects can be explained, the relatively poor cost and schedule performance of the larger projects suggests that again, the dataset may not be representative of data typically found in the CII BM&M Program.

By project nature, owner modernization projects exhibited the best overall cost performance as indicated by the cost growth metrics, which as noted above illustrates exceptional characteristics of the dataset. They also reported better safety performance than others. Grass roots projects having less impacts from interferences and interface complexities do report more predictable cost and schedule performance according to the delta metrics. Additions, despite many of the issues common to modernization projects, actually reported better performance on a few schedule and change metrics. It is possible that other factors are influencing the somewhat surprising results seen by project nature. Recognizing the complexities caused by additions and modernizations, owners may be requiring performance enhancing procedure to include more sophisticated IT systems. Some evidence of this will be discussed later in this chapter when technology use is presented.

Table 3-1. Summary of Mean Performance Outcomes – CII Owners

Performance Metrics[1]	All Owners	By Industry Group		By Cost Category (millions)			By Project Nature		
		Buildings[3]	Industrial[4]	<$15	$15 to $50	>$50	Addition	Grass	Modern
COST									
Project Cost Growth	-0.001	0.023*	-0.079	0.029	-0.057	0.027	0.000	0.019	-0.020
Project Budget Factor	0.924	0.950*	0.917	0.957	0.884	0.917	0.943	0.932	0.903
Delta Project Cost Growth	0.097	0.091*	0.099	0.111	0.075	0.115	0.093	0.082	0.112
Delta Project Budget Factor	0.109	0.081*	0.116	0.146	0.082	0.104	0.094	0.089	0.135
Design Phase Cost Growth[2]	0.042	0.129*	0.013	0.044*	0.061	-0.007*	0.063*	0.002*	0.055
Procurement Phase Cost Growth[2]	-0.075	C.T.	-0.086	-0.099*	-0.065*	C.T.	-0.042*	C.T.	-0.111
Construction Phase Cost Growth[2]	0.029	0.032*	0.033	-0.034	0.056	0.073*	0.104	0.043	-0.033
Startup Phase Cost Growth[2]	-0.049	C.T.	-0.052	-0.102*	-0.010*	C.T.	C.T.	C.T.	-0.022*
Pre-Project Planning Phase Cost Factor[2]	0.026	C.T.	0.027	0.021*	0.029*	0.025*	0.027*	0.022*	0.029*
Design Phase Cost Factor[2]	0.090	0.071*	0.097	0.081	0.094	0.095*	0.081*	0.090	0.097
Procurement Phase Cost Factor[2]	0.168	C.T.	0.177	0.171*	0.191	C.T.	0.156*	0.169*	0.175
Construction Phase Cost Factor[2]	0.721	0.909*	0.667	0.682	0.708	0.794*	0.706	0.818	0.649
Startup Phase Cost Factor[2]	0.036	C.T.	0.039	0.040*	0.032*	C.T.	0.036*	0.032*	0.038*
SCHEDULE									
Project Schedule Growth	0.114	0.188*	0.100	0.132	0.081	0.151	0.094	0.115	0.128
Project Schedule Factor	1.027	0.971*	1.039	1.023	1.027	1.033	1.053	1.039	0.997
Overall Project Duration (week)	119.9	141.4*	114.0	75.0	119.9	183.3	104.6	166.6	96.5
Design-Startup Duration[2] (week)	95.1	114.5*	90.1	54.3	102.5	142.1	84.9	129.0	78.3
Construction Phase Duration[2] (week)	66.0	74.9*	63.9	30.4	70.4	99.0	54.7	98.5	47.5
Startup Phase Duration[2] (week)	12.429	3.229*	15.025	6.3	13.952	22.34*	11.023*	17.273	9.577
Delta Project Schedule Growth	0.185	0.218*	0.182	0.250	0.139	0.181	0.160	0.147	0.236

[1]Metric definitions are provided in Appendix B.
[2]Phase definitions are provided in Appendix C.
[3]n=19
[4]n=74
Shading indicates best performance within category
* Statistical warning indicator. See Appendix A.
C.T. Data withheld per CII Confidentiality. See Appendix A.

Table 3-1. Summary of Mean Performance Outcomes – CII Owners (continued)

Performance Metrics[1]	All Owners	By Industry Group		By Cost Category (millions)			By Project Nature		
		Buildings[3]	Industrial[4]	<$15	$15 to $50	>$50	Addition	Grass	Modern
SCHEDULE (Continued) Delta Project Schedule Factor	0.152	0.166*	0.151	0.187	0.134	0.135	0.155	0.136	0.162
Construction Phase Schedule Growth[2]	0.054	C.T.	0.052	0.001*	0.041	0.128*	0.039	0.124	-0.002
Startup Phase Schedule Growth[2]	0.282	C.T.	0.326	0.245*	0.217*	0.423*	0.402*	0.150*	0.289
Pre-Project Planning Phase Duration Factor[2]	0.211	C.T.	0.207	0.241*	0.190	0.214	0.176	0.206	0.254
Design Phase Duration Factor[2]	0.326	0.302*	0.331	0.270	0.378	0.305	0.307	0.310	0.358
Procurement Phase Duration Factor[2]	0.408	C.T.	0.434	0.312*	0.470	0.444*	0.391*	0.390*	0.435
Construction Phase Duration Factor[2]	0.529	0.503*	0.535	0.413	0.580	0.571	0.514	0.579	0.495
Startup Phase Duration Factor[2]	0.193	C.T.	0.205	0.128	0.256	0.202*	0.166*	0.162*	0.239
SAFETY TRIR	1.031	0.868*	1.030	0.381	1.232	1.622*	0.933	1.527	0.729
DART	0.058	0.058*	0.061	0.030	0.067*	0.091*	0.041*	0.181*	0.000
CHANGES Change Cost Factor	0.080	0.078*	0.083	0.070	0.073	0.103	0.074	0.086	0.078
Change Schedule Factor	0.126	C.T.	0.100	C.T.	0.090*	0.143*	C.T.	0.110*	0.168*
REWORK Rework Cost Factor	0.012	0.004*	0.014	0.013	0.009	C.T.	0.014*	0.005*	0.014*

[1]Metric definitions are provided in Appendix B.
[2]Phase definitions are provided in Appendix C.
[3]n=19
[4]n=74
Shading indicates best performance within category
* Statistical warning indicator. See Appendix A.
C.T. Data withheld per CII Confidentiality. See Appendix A.

3.1.3 Performance Outcomes – CII Contractors

Table 3-2 summarizes contractor project performance for each analysis category. All projects are drawn from the industrial sector; however, given that there are only 44 projects, division by cost and nature categories produces very small samples and requires the suppression of many results. As such, few conclusions can be drawn from the breakouts, although there are some opportunities for comparisons to the owner data and general conclusions are possible on overall contractor project performance.

In general, contractor performance for industrial projects is very good. Cost growth of -3.5 % is excellent, even exceeding the good performance of owners. On average the reported schedule performance of the contractors is also excellent and is about 10 % better than owners. A closer examination of the delta metrics reveals that contractors cost and schedule performance are also more predictable than that of the owners. The contractor safety metric for recordable incidences is more than twice as good as that of owners while the lost time DART rates (Days Away, Restricted, or Transfer case incidence rate) tend to be similar. A notable difference in the owner and contractor datasets is the difference in project size. Contractor projects on average are 50 % larger than owner projects.

While very little can be said from the cost category and project nature breakouts of Table 3-2, the shading pattern of schedule growth metrics (shading indicating better performance) appears as expected.

Table 3-2. Summary of Mean Performance Outcomes – CII Contractors

Performance Metrics[1]	All Contractors	By Industry Group		By Cost Category (millions)			By Project Nature		
		Buildings[3]	Industrial[4]	<$15	$15 to $50	>$50	Addition	Grass	Modern
COST									
Project Cost Growth	-0.032		-0.035	-0.014*	-0.077*	-0.014*	-0.055*	-0.011*	C.T.
Project Budget Factor	0.927		0.922	0.913*	0.903*	0.957*	0.916*	0.945*	C.T.
Delta Project Cost Growth	0.081		0.082	0.064*	0.105*	0.081*	0.083*	0.089*	C.T.
Delta Project Budget Factor	0.089		0.091	0.090*	0.115*	0.068*	0.096*	0.078*	C.T.
Design Phase Cost Growth[2]	0.026		0.025	0.021*	C.T.	0.063*	-0.008*	0.063*	C.T.
Procurement Phase Cost Growth[2]	-0.055		-0.053	-0.039*	C.T.	-0.021*	-0.093*	-0.031*	C.T.
Construction Phase Cost Growth[2]	-0.048		-0.055	C.T.	C.T.	-0.046*	-0.045*	-0.078*	C.T.
Startup Phase Cost Growth[2]	C.T.		C.T.	C.T.	C.T.	C.T.	C.T.	C.T.	C.T.
Pre-Project Planning Phase Cost Factor[2]	0.072*		0.072*	C.T.	C.T.	C.T.	C.T.	C.T.	C.T.
Design Phase Cost Factor[2]	0.160		0.163	C.T.	0.168*	0.165*	0.133*	0.163*	C.T.
Procurement Phase Cost Factor[2]	0.332		0.330	0.250*	C.T.	0.357*	0.342*	0.352*	C.T.
Construction Phase Cost Factor[2]	0.477		0.474	C.T.	C.T.	0.489*	0.503*	0.462*	C.T.
Startup Phase Cost Factor[2]	C.T.		C.T.	C.T.	C.T.	C.T.	C.T.	C.T.	C.T.
SCHEDULE									
Project Schedule Growth	-0.007		-0.007	-0.002*	C.T.	-0.005*	0.001*	-0.023*	C.T.
Project Schedule Factor	0.953		0.947	0.927*	0.962*	0.976*	0.956	0.946*	C.T.
Overall Project Duration (week)	90.4		90.9	64.3*	96.9*	117.4*	83.6*	100.8*	C.T.
Design-Startup Duration[2] (week)	80.2		80.2	53.4*	87.6*	107.4*	76.4*	94.5*	C.T.
Construction Phase Duration[2] (week)	62.9		60.7	C.T.	C.T.	70.3*	78.1*	63.9*	C.T.
Startup Phase Duration[2] (week)	8.071		8.456	C.T.	C.T.	C.T.	8.943*	C.T.	C.T.
Delta Project Schedule Growth	0.080		0.073	0.076*	0.077*	0.087*	0.063*	0.098*	C.T.

[1]Metric definitions are provided in Appendix B.
[2]Phase definitions are provided in Appendix C.
[3]n=0
[4]n=42

Shading indicates best performance within category
* Statistical warning indicator. See Appendix A.
C.T. Data withheld per CII Confidentiality. See Appendix A.

Table 3-2. Summary of Mean Performance Outcomes – CII Contractors (continued)

Performance Metrics[1]	All Contractors	By Industry Group		By Cost Category (millions)			By Project Nature		
		Buildings[3]	Industrial[4]	<$15	$15 to $50	>$50	Addition	Grass	Modern
SCHEDULE (Continued) Delta Project Schedule Factor	0.085		0.085	0.111*	0.048*	0.082*	0.078	0.088*	C.T.
Construction Phase Schedule Growth[2]	-0.001		-0.001	C.T.	C.T.	0.018*	-0.031*	0.020*	C.T.
Startup Phase Schedule Growth[2]	-0.013*		-0.013*	C.T.	C.T.	C.T.	C.T.	C.T.	C.T.
Pre-Project Planning Phase Duration Factor[2]	0.244		0.244	C.T.	C.T.	0.274*	C.T.	C.T.	C.T.
Design Phase Duration Factor[2]	0.580		0.568	0.656*	C.T.	0.580*	0.643*	0.575*	C.T.
Procurement Phase Duration Factor[2]	0.549		0.549	0.569*	C.T.	0.595*	C.T.	0.565*	C.T.
Construction Phase Duration Factor[2]	0.607		0.595	C.T.	C.T.	0.623*	0.770*	0.589*	C.T.
Startup Phase Duration Factor[2]	0.120*		0.120*	C.T.	C.T.	C.T.	C.T.	0.139*	C.T.
SAFETY TRIR	0.468		0.468	C.T.	C.T.	0.638*	0.456*	0.407*	C.T.
DART	0.080		0.080	C.T.	C.T.	C.T.	C.T.	C.T.	C.T.
CHANGES Change Cost Factor	0.060		0.063	0.064*	0.074*	0.044*	0.052*	0.059	C.T.
Change Schedule Factor	0.126*		0.117*	C.T.	C.T.	C.T.	C.T.	C.T.	C.T.
REWORK Rework Cost Factor	0.010*		0.011*	C.T.	C.T.	C.T.	0.012	C.T.	C.T.

[1]Metric definitions are provided in Appendix B.
[2]Phase definitions are provided in Appendix C.
[3]n=0
[4]n=42
Shading indicates best performance within category
* Statistical warning indicator. See Appendix A.
C.T. Data withheld per CII Confidentiality. See Appendix A.

3.1.4 Degree of A/I Tech Practice Use – CII Owners

This section presents the assessment and use of automation and integration technologies by CII owners. Three indices, A/I Tech (automation and integration technologies), A Tech (automation technologies), and I Tech (integration technologies), are developed to assess the degree of use of automation and integration technologies for the CII task work functions depicted in Table 2-4 and discussed in Chapter 2. The A/I Tech index represents an un-weighted aggregation of the level of automation for each function and the level of integration across each function scored on a scale of 0 to 10 with higher scores indicating greater automation and integration. The A Tech index assesses the level of automation only and the I Tech index assesses the level of integration only, again scored on a scale of 0 to 10. The purpose for separating the automation and integration scores was to better enable assessment of interoperability through the I Tech metric. Survey questions and response scales for the A/I Tech indices are presented below and details of the calculation method for the indices are described in Appendix D.

Assessment of the level of automation and integration technologies use by surveying work functions represents a methodological change for CII. Previous research performed at CII assessed technology use by surveying specific technologies applied on projects rather than examining work functions. Results of those studies proved problematic as technology changed. Since work functions remain essentially the same over time, assessment of the degree of technology use for each work function offers the potential for more consistent assessments and improved trend analyses.

Table 3-3 presents the work functions and response scales used to assess both the level of automation and the level of integration of the work functions. Respondents are asked to assess both their level of automation and then integration of each task work function using a 5 point response scale. The 5 point response scale has proven popular within CII benchmarking in that most respondents are comfortable with a median point and a couple of options to either side. Response levels are defined and anchored by common and generic technologies that respondents are expected to be able to identify with for most any project, such as “2D/3D CAD,” “Office equivalent systems,” and “integrated databases” for automation. For integration, response levels are defined generically again with choices such as “manual information transfer,” “integration with significant human intervention,” and “fully integrated with network accessible systems.” In retrospect, level definitions for automation and integration are likely the correct approach, however, specific definitions for the higher level automation responses may need clarification. Feedback from training sessions with CII companies on use of these metrics has indicated difficulties with understanding some definitions and potential for confusion. Another possible problem for respondents is the high level at which the task work functions are defined. While most respondents are comfortable with assessing the degree of automation of functions such as “Supply Management” or “Schedule System,” the CII questionnaire surveys project management sub-functions of “Coordination System,” and “Communications System” which respondents have more difficulty in identifying as defined systems within their company.

Table 3-3 Task/Work Functions and Response Scales

Referring to the use levels below, indicate how well for this project, the tasks/work functions were automated (or integrated).

Task/Work Functions	1	2	3	4	5	NA	UNK
Business planning and analysis							
Conceptual definition & design							
Project (discipline) definition & facility design							
Supply management							
Project management							
Coordination system							
Communications system							
Cost system							
Schedule system							
Quality system							
Off-site/pre-construction							
Construction							
As-built documentation							
Facility start-up & life cycle support							

Use Levels

Automation	**Integration**
Level 1(None/Minimal): Little or no utilization beyond e-mail.	**Level 1(None/Minimal):** Little or no integration of electronic systems/applications.
Level 2 (Some): "Office" equivalent software, 2D CAD for detailed design.	**Level 2 (Some):** Manual transfer of information via hardcopy of email.
Level 3 (Moderate): Standalone electronic/automated engineering discipline (3D CAD) and project services systems.	**Level 3 (Moderate):** Manual and some electronic transfer between automated systems.
Level 4 (Nearly Full): Some automated input/output from multiple databases with automated engineering discipline design and project services systems.	**Level 4 (Nearly Full):** Most systems are integrated with significant human intervention for tracking inputs/outputs.
Level 5 (Full): Fully or nearly fully automated systems dominate execution of all work functions.	**Level 5 (Full):** All information is stored on a network system accessible to all automation systems and users. All routine communications are automated. The automated process and discipline design systems are fully integrated into 3D design, supply management, and project services systems (cost, schedule, quality, and safety).

Owner A/I Tech scores are summarized in Table 3-4. Industrial projects reported higher A/I Tech scores than building projects which is consistent with expectations and findings of previous CII research where the greater complexity of industrial projects correlated with increased use of technology. The average size of industrial and building projects in the owner dataset happens to be very similar at approximately $48 million total installed cost suggesting that cost, or project size, is not driving observed differences in A/I Tech use. The similarity in project size between buildings and industrial projects is another indication of the uniqueness of this particular owner sample. Again, the relatively small sample size for building projects warrants caution.

Also of interest, small and midsize projects by cost category reported somewhat more use of A/I Tech than did larger projects. This is counterintuitive and bears more investigation in future datasets since previous studies at CII have shown good correlations between project size and technology use with larger project making greater use of technology. It would be convenient to dismiss this observation based on a lack of statistical significance; however, the pattern is consistent throughout the data distribution. Similarly, addition and modernization projects reported more technology use than grass roots projects producing another inconsistency with earlier research. Apparent from the analysis thus far though is a correlation between A/I Tech and performance. The better performing groups in Table 3-1 tend to be the groups reporting greater A/I Tech scores in Table 3-4. This will be examined in greater detail in Chapter 4.

Table 3-4. Summary of A/I Tech Practice Use – CII Owners

Percentile Ranking	All Owners	By Industry Group		By Cost Category (millions)			By Project Nature		
		Buildings	Industrial	<$15	$15 to $50	>$50	Add	Grass	Modern
100 %	9.688	7.5*	9.688	9.688	9.688	7.5	9.688	8.452	9.688
90 %	7.183	6.737*	7.385	7.606	6.931	7.003	7.612	7.094	7.138
75 %	6.010	5.326*	5.577	5.000	6.178	5.849	6.010	5.691	5.745
50 %	4.050	3.798*	4.050	3.798	4.351	4.183	4.082	3.894	4.392
25 %	3.368	3.561*	3.341	3.385	3.726	2.716	3.665	2.716	3.568
10 %	2.558	2.837*	2.558	2.967	2.875	1.917	3.370	2.125	2.911
0 %	0	2.083*	0	1.827	2.083	0	2.692	0	1.827
Mean	4.638	4.435*	4.624	4.654	4.843	4.276	4.911	4.249	4.786
s.d.	1.930	1.575*	2.002	2.011	1.792	2.075	1.932	2.054	1.809
n	94	18*	74	30	40	24	26	32	36

Note: Appendix D describes Automation/Integration Technology index calculations
Shading indicates best performance within category * Statistical warning indicator
n indicates the number of projects

Tables 3-5 and 3-6 summarize automation technology (A Tech) use and integration technology (I Tech) use for owners, respectively. In general the patterns in the two tables are quite similar with those in Table 3-4. Perhaps the most important observation from Tables 3-5 and 3-6 is that integration scores appear to be higher than automation. If the indices were statistically comparable this would not seem logical since it is necessary to automate a work function before it can be integrated. A simple explanation for the differences is that the two indices are based upon different response level definitions as shown in Table 3-3.

Table 3-5. Summary of A Tech Practice Use – CII Owners

Percentile Ranking	All Owners	By Industry Group		By Cost Category (millions)			By Project Nature		
		Buildings	Industrial	<$15	$15to$50	>$50	Add	Grass	Modern
100 %	9.423	8.636*	9.423	9.423	9.375	8.636	9.423	8.636	9.375
90 %	7.5	6.625*	7.5	7.577	7.5	7.417	7.885	7.5	7.212
75 %	5.385	5.313*	5	4.948	6.042	6.042	5.817	5.729	5.048
50 %	3.542	4.209*	3.462	3.163	3.854	3.636	4.231	3.409	3.854
25 %	2.500	2.5*	2.692	2.548	2.909	2.5	2.692	2.5	2.937
10 %	2.292	2.442*	2.292	2.292	2.477	2.250	2.219	2.5	2.3
0 %	1.591	2.045*	1.591	2.083	1.731	1.591	1.731	1.591	2.273
Mean	4.266	4.209*	4.199	4.051	4.441	4.242	4.231	4.2	4.348
s.d.	2.054	1.933*	2.065	2.150	1.982	2.115	2.338	2.045	1.895
n	93	18*	73	30	40	23	26	31	36

Note: Appendix D describes Automation/Integration Technology index calculations
Shading indicates best performance within category * Statistical warning indicator

Table 3-6. Summary of I Tech Practice Use – CII Owners

Percentile Ranking	All Owners	By Industry Group		By Cost Category (millions)			By Project Nature		
		Buildings	Industrial	<$15	$15to$50	>$50	Add	Grass	Modern
100 %	10	7.5*	10	10	10	7.5	10	8.636	10
90 %	7.667	7.063*	8.5	8.865	7.894	7.5	8.942	7.5	7.727
75 %	6.154	5.288*	6.154	5.288	6.306	6.165	6.154	5.708	6.478
50 %	5	5*	5.126	5	5	4.904	5	5	5
25 %	3.636	3.217*	3.75	3.665	3.923	2.656	4.428	2.708	3.602
10 %	2.5	2.5*	2.538	2.951	2.654	1.589	3.923	2.115	2.7
0 %	0	2.115*	0	1.346	2.115	0	2.692	0	1.346
Mean	5.073	4.675*	5.126	5.232	5.308	4.495	5.581	4.499	5.202
s.d.	2.118	1.621*	2.234	2.167	1.989	2.238	1.934	2.195	2.118
n	93	18*	73	30	39	24	26	31	36

Note: Appendix D describes Automation/Integration Technology index calculations
Shading indicates best performance within category * Statistical warning indicator

It is useful to briefly compare Table 3-4 to findings from previous CII research performed for NIST and published as GCR 99-786 and GCR 01-828. The first report contained data collected in 1997 and 1998 and the second report contained data collected between 1997 and 1999. These studies surveyed and reported on the use of 4 distinct technologies: 3D

CAD, EDI, bar coding and integrated databases. The indices produced in these studies, named D/I Tech for design and information technologies, were scored similarly to A/I Tech using a scale of 0 to 10. It is not reasonable to compare the values in Table 3-4 to the values in the previous reports given the differences in surveying technologies and work functions. However, both NIST GCRs indicated that 25 % of respondents reported no use of the technologies. The survey for A/I Tech data collected responses from 2002 through 2004 and surveyed a broader set of technologies through their application on project work functions. An interesting contrast with the previous studies is that only 1 project out of 139 reported no use of technologies. This may provide some anecdotal evidence to support that technology use is expanding within the industry.

3.1.5 Degree of A/I Tech Practice Use – CII Contractors

Table 3-7 summarizes the A/I Tech practice use for contractors. These scores are based on the same work functions and response scales presented in Table 3-3. By cost category, larger projects generally used A/I Tech more than small and midsize projects. By project nature grass roots reported slightly more use, but the small sample makes it impossible to conclude any significance. These findings are different from those shown in the owners' data but are much more consistent with previous CII research findings. The mean value of A/I Tech use for all projects in the contractor data is 5.596, whereas the mean value for all owners was 4.638.

Table 3-7. Summary of A/I Tech Practice Use – CII Contractors

Percentile Ranking	All Contractors	By Industry Group		By Cost Category (millions)			By Project Nature		
		Buildings	Industrial	<$15	$15to$50	>$50	Add	Grass	Modern
100 %	10	C.T.	10	9.231*	9.231*	10*	9.231*	10*	C.T.
90 %	8.964	C.T.	9.082	7.284*	9.228*	7.646*	9.231*	7.208*	C.T.
75 %	6.547	C.T.	6.583	6.198*	7.925*	6.372*	7.857*	6.380*	C.T.
50 %	5.481	C.T.	5.581	4.904*	5.553*	5.682*	5*	5.877*	C.T.
25 %	4.322	C.T.	4.535	4.031*	3.698*	4.891*	3.75*	4.827*	C.T.
10 %	3.542	C.T.	3.547	3.347*	2.691*	4.545*	2.98*	3.688*	C.T.
0 %	1.094	C.T.	2.5	2.5*	1.094*	3.542*	1.094*	2.596*	C.T.
Mean	5.596	C.T.	5.703	5.282*	5.623*	5.909*	5.640*	5.742*	C.T.
s.d.	2.016	C.T.	1.913	1.772*	2.785*	1.587*	2.529*	1.656*	C.T.
n	43	0	42	16*	12*	15*	19*	18*	6

Note: Appendix D describes Automation/Integration Technology index calculations
Shading indicates best performance within category * Statistical warning indicator
C.T. Data withheld per CII Confidentiality. See Appendix A.

Tables 3-8 and 3-9 summarize A Tech and I Tech use for contractors, respectively. The results in the tables are similar to those in Table 3-7. One difference is that I Tech use (Table 3-9) among small, midsize, and large projects shows very comparable scores, suggesting a more uniform application of integration technologies across project sizes. However, the small sample sizes require caution in interpretation and a need for follow-up investigation.

Table 3-8. Summary of A Tech Practice Use – CII Contractors

Percentile Ranking	All Contractors	By Industry Group		By Cost Category (millions)			By Project Nature		
		Buildings	Industrial	<$15	$15to$50	>$50	Add	Grass	Modern
100 %	10	C.T.	10	9.038*	9.038*	10*	9.038*	10	C.T.
90 %	8.781	C.T.	8.910	7.143*	9.038*	7.65*	9.038*	7.575*	C.T.
75 %	6.830	C.T.	6.853	6.354*	7.885*	6.979*	7.5*	6.719*	C.T.
50 %	5	C.T.	5.125	4.712*	5.043*	5.577*	5*	5.629*	C.T.
25 %	3.902	C.T.	4.048	2.5*	3.642*	4.896*	3.902*	4.392*	C.T.
10 %	2.5	C.T.	2.5	2.5*	2.519*	4.035*	2.5*	2.635*	C.T.
0 %	0.938	C.T.	2.045	2.045*	0.938*	2.917*	0.938*	2.5*	C.T.
Mean	5.322	C.T.	5.426	4.773*	5.433*	5.818*	5.489*	5.467*	C.T.
s.d.	2.192	C.T.	2.107	2.092*	2.752*	1.776*	2.467*	2.019*	C.T.
n	43	0	42	16*	12*	15*	19*	18*	6

Note: Appendix D describes Automation/Integration Technology index calculations
Shading indicates best performance within category * Statistical warning indicator
C.T. Data withheld per CII Confidentiality. See Appendix A

Table 3-9. Summary of I Tech Practice Use – CII Contractors

Percentile Ranking	All Contractors	By Industry Group		By Cost Category (millions)			By Project Nature		
		Buildings	Industrial	<$15	$15to$50	>$50	Add	Grass	Modern
100 %	10	C.T.	10	9.444*	9.423*	10*	9.423*	10*	C.T.
90 %	9.413	C.T.	9.418	8.67*	9.418*	7.958*	9.423*	8.083*	C.T.
75 %	7.083	C.T.	7.083	6.771*	7.969*	6.67*	8.229*	7.074*	C.T.
50 %	5.385	C.T.	5.42	5.252*	6.023*	5.455*	5.192*	5.568*	C.T.
25 %	4.730	C.T.	4.830	4.922*	3.094*	5.096*	3.75*	5*	C.T.
10 %	3.025	C.T.	3.188	3.438*	2.550*	4.375*	2.5*	4.042*	C.T.
0 %	1.25	C.T.	2.5	2.5*	1.25*	3.75*	1.25*	2.5*	C.T.
Mean	5.871	C.T.	5.420	5.821*	5.826*	5.960*	5.786*	5.996*	C.T.
s.d.	2.151	C.T.	2.051	2.031*	2.933*	1.640*	2.679*	1.889*	C.T.
n	43	0	42	16*	12*	15*	19*	18*	6

Note: Appendix D describes Automation/Integration Technology index calculations
Shading indicates best performance within category * Statistical warning indicator
C.T. = Data withheld per CII Confidentiality. See Appendix A.

3.2 Southeastern U.S. Contractors Dataset

3.2.1 Data Description

Figures 3-5 and 3-6 describe the industry sectors and company sizes for 74 contractors in the Southeastern U.S. that submitted data on performance and technology use in early 2003. This dataset reports company level data whereas the CII data are project level. As shown in Figure 3-5, most of data are from the building industry. Figure 3-6 categorizes the companies based on their revenue. 50 % of the firms had more than $50 million of revenue; the remaining are smaller enterprises. As such, this dataset describes companies, and likely projects, much smaller than those represented by the CII dataset.

Figure 3-5. Southeastern U.S. Contractors Dataset by Industry Sectors

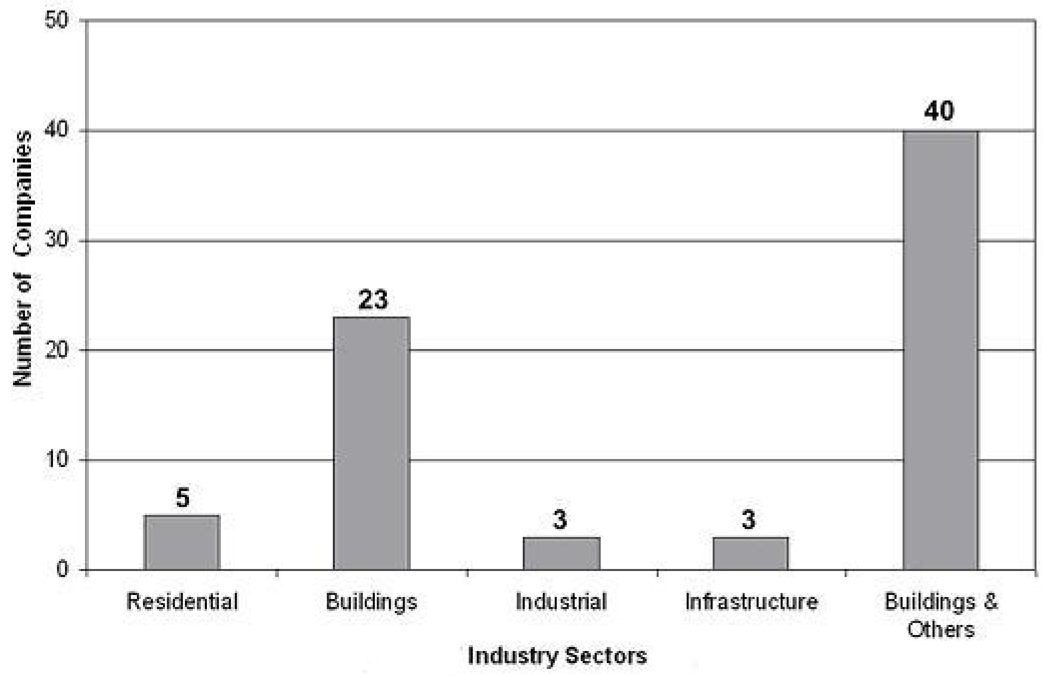
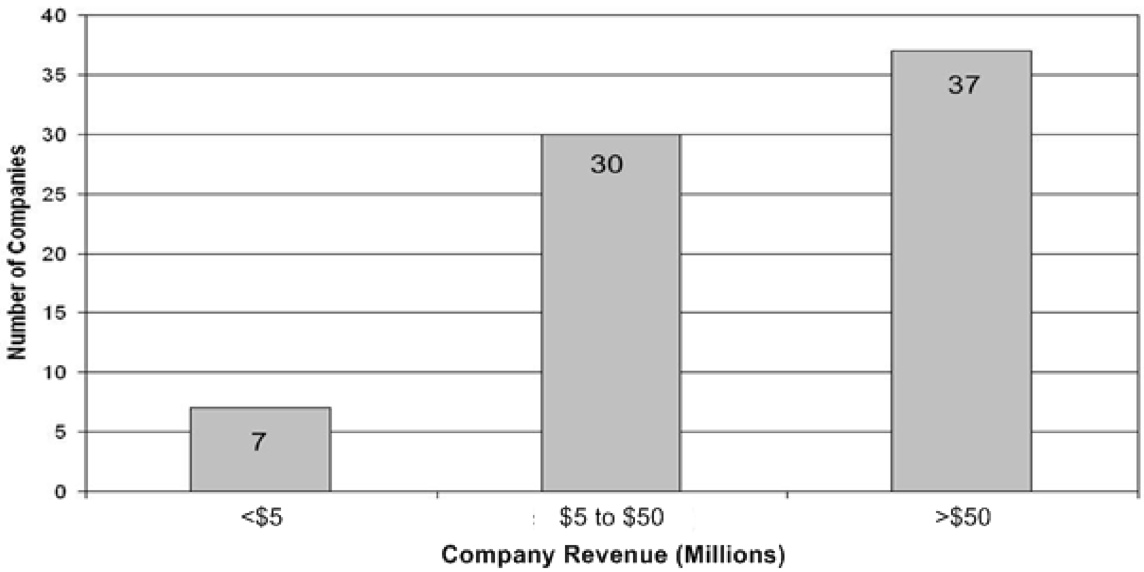


Figure 3-6. Southeastern U.S. Contractors Dataset by Revenue



3.2.2 Performance Outcomes – Southeastern U.S. Contractors Dataset

Table 3-10 shows performance outcomes for the contractors in this dataset. Only company revenue can be categorized; project nature data were not collected. Performance data were obtained for cost, schedule, safety, customer satisfaction, and profitability and although the metrics are generally self-explanatory, the definitions are provided in Appendix B, Section B.2. Since all companies did not report complete performance data for each metric, there are fewer than 74 samples per metric as indicated by the n value in the table. As shown in Table 3-10, small companies reported better cost and profitability performance, whereas large companies reported better schedule, safety, and customer satisfaction performance. Note that for all Table 3-10 metrics except EMR, large values reflect better performance.

Table 3-10. Summary of Mean Performance Outcomes – Southeastern U.S. Contractors Dataset

Performance Metrics[1]	n	All Companies	Company Revenue (millions)		
			< $5	$5~$50	> $50
Percent on/under budget	68	81.6	85.7 (7)	84.2 (27)	78.8 (34)
Percent on/ahead of schedule	68	79.3	72.9 (7)	79.8 (28)	80.2 (33)
Safety (EMR)	34	0.699	0.763 (4)	0.754 (9)	0.663 (21)
Percent Repeat Business	66	60.1	64.3 (6)	53.3 (28)	65.3 (32)
Profit as Percent of Sales	45	3.67	5.33 (5)	3.78 (21)	3.12 (19)

Shading indicates the best performances within category (n) Number of Companies
[1]Metric definitions are provided in Appendix B, section B.2.

3.2.3 Degree of IT Practice Use – Southeastern U.S. Contractors Dataset

Table 3-11 below presents a sample of the 48 work functions and the response scales used to assess both the level of automation and the level of integration of the work functions for the Southeastern U.S. Contractors dataset. Respondents were asked to respond to one of three levels where level 1 indicated no automation or integration, level 2 indicated automation only, and level 3 integration only. Responses were collected at the company level and in cases where multiple responses were received per company; these were averaged to obtain an aggregated response for the company. A comparison of these functions and response scale to that of the CII dataset is provided at the end of this chapter.

Table 3-11 Sample Work Functions and Response Scales

PART 3: Degree of Technology Use

Please indicate the level of Degree of Technology Use for each task in the different phases of a project as shown in the table below. Where:
LEVEL 1: No electronic tools or commonly used electronic tools
LEVEL 2: Specialized stand-alone electronic tools
LEVEL 3: Integrated electronic tools
Please refer to the last page of this questionnaire for detailed definitions and examples of the Degree of Technology Use

ID	Task	Degree of Technology Use				
	Procurement Phase	**Don't know**	**1**	**2**	**3**	**NA**
1	Determine the lead time required to order equipment and materials					
2	Conduct a quantity survey of drawings					

Technology use for the Southeastern U.S. Contractors is depicted in Table 3-12 by the IT index score. Conceptually, the index is similar to the one computed for the CII dataset. The index is an un-weighted aggregation of scores for each of 48 individual work functions shown in Table 2-5. Calculation of the IT index score is described in Appendix D. As shown in Table 3-12, larger companies showed the highest level of IT use, similar to the reported use in the CII contractor dataset. Note, however, that there are only 7 samples in the small firm category.

Table 3-12. Summary of IT Index Scores

Percentile Ranking	All Companies	Company Revenue (millions)		
		<$5	$5 to $50	>$50
100 %	8.205	3.830	6.667	8.205
90 %	5.636	3.555	5.160	5.984
75 %	4.392	2.847	3.988	4.840
50 %	3.421	2.321	3.313	3.930
25 %	2.250	2.082	2.277	2.768
10 %	1.185	1.578	1.135	1.384
0 %	0.484	1.061	0.484	0.690
Mean	3.496	2.439	3.221	3.930
s.d.	1.672	0.916	1.502	1.804
n	73	7	30	36

Note: Appendix D describes how the IT index is calculated.
Shading indicates the best performances within category.

3.3 Comparison of CII and Southeastern U.S. Contractors Survey Instruments

A brief comparison of the survey instruments used for the CII dataset and that of the Southeastern U.S. Contractors is useful for an understanding of responses received and findings presented in Sections 3.1 and 3.2 above. This comparison is summarized in Table 3-13 below.

Survey responses at company and project level can produce very different results even within the same company. CII has established through ongoing research that perceptions of both practice use and performance vary considerably at the project level from that of the company level. Often company level responses reflect policy or the opinions of management whereas project level responses tend to reflect actual experiences unless there is an effort to bias responses based on the expected use of the survey. Multiple responses are useful for obtaining an average or consensus response. Multiple responses, however, are not generally feasible in a benchmarking setting such as CII's.

Table 3-13. Survey Instrument Comparison

	CII	SE U.S. Contractors
Respondent Level	Project	Company
Number of Respondents	1 per project	Multiple
Respondent Type	Owner[1] & Contractor	Contractor
Industry Groups	Building & Industrial	Predominately Building
Work Functions & Level	13 – High Level	48 – Low Level
Response Scales	5 Point – Separate for Automation & Integration	3 Point – Combined for Automation & Integration
Performance Metrics	High Level, Objective & Quantitative	Mostly High Level & Subjective

[1] Mostly Owner

The quality of data differs by respondent type. Many owner organizations have outsourced many of their traditional project development and management functions and often do not have the resources to respond accurately to surveys as used in this study. In many cases owners are dependent on contractors to provide reliable responses, particularly in the cost-conscious industrial sectors.

The level at which work functions are surveyed can have significant impacts on the quality of data. In general, data for work functions at lower levels which can be related to daily work tasks such as "refine the preliminary budget estimate" or "develop the milestone schedule" produce more accurate survey assessments since they are easier to relate to for respondents. The higher the level of the work function such as "conceptual definition & design" or "construction," the more complex the process and more noise is present complicating the ability to accurately respond to questions like assessing the degree of automation or integration. One-off surveys can often include more detail; however, ongoing data collection instruments such as those used in benchmarking by necessity tend to focus on the critical few questions, which often drive definition to higher levels.

Response scales can greatly affect the quality of the data as well. CII benchmarking experience confirms advantages of simplistic 5 point Likert-type scales when collecting subjective responses such as opinions on the degree of automation or integration. Definition of anchor points within the scale is critical for minimizing confusion and obtaining more accurate responses. Examination of the 3-point scale used in the Southeastern U.S. Contractors survey reveals that it is actually very different from the CII Likert-type scales in that it actually measures no technology use, automation use, or integration use, rather than degree of use of IT. These questions are structured to produce a 3 bin response in which either no technology is used, there is some technology use, or the work function is fully automated and integrated. CII definitions suggest that automation is a step in the integration process and that to be integrated; it has to be at least partially automated. The Southeastern U.S. Contractors dataset does not follow the CII definitions of automation and integration, but is generally compatible with the CII approach. Another salient difference between the datasets is that whereas the CII questionnaire asks questions at a general level with 13 work functions for both automation and integration, the Southeastern contractors questionnaire assesses 48 specific work functions. Thus the CII dataset allows more fine-grained assessment of IT use per work function while the Southeastern U.S. Contractors dataset allows more detailed assessment of project work functions.

Finally, performance metrics differ very much between the two datasets. While CII metrics are for the most part high level, they are quantitative and the values are calculated from hard data maintained in project files such as cost and schedule data. The nature of the Southeastern U.S. Contractors performance metrics such as the "percentage of projects completed on or under budget," if calculated from actual data, will produce continuous scale data useful for more rigorous analysis. Without collecting the actual project data to support such calculations though, it is difficult to know if the respondent simply provides a guess at the number requested. There are advantages and disadvantages for both data collection and analysis with these type data.

4. CORRELATIONS – TECHNOLOGY USE AND PERFORMANCE

This chapter presents the correlations of A/I Tech usage and performance for the CII dataset and the correlation of IT index usage and performance for the Southeastern U.S. Contractors dataset. Since both A/I Tech and IT index measure the use of information technologies from very different perspectives, the former at project level and the latter at company, their correlations with their respective performance metrics provide interesting and complementary indicators of potential value derived through association.

In Chapter 3 distributions of A/I Tech, A Tech, and I Tech indices were presented from CII data. The first two parts of this chapter present and describe analyses based upon correlations between these indices and performance metrics for CII owners and contractors. Section 4.3 describes correlation analyses for contractors in the Southeastern U.S. Contractors dataset. The chapter concludes with a discussion of specialty indices based on the mapping exercises described in Chapter 2.

Where sufficient data are available correlations are shown through quartile analysis. The 4th quartile indicates low A/I Tech use, whereas the 1st quartile indicates high use of A/I Tech. The smaller data samples are presented and analyzed in low and high halves rather than in quartiles. The first two columns list the performance metrics and the number of projects available for analysis. The third through sixth columns of the tables (for quartile analysis or third and fourth columns for analysis by halves) show the mean value for each performance metric by category of A/I Tech use. For quartile analysis, the 3rd and 4th quartiles are characterized as the investment stage of A/I Tech use, in which owners and contractors have begun to use the technologies, but have not necessarily experienced measurable benefit from them in terms of improved performance. The 1st and 2nd quartiles are characterized as the benefit stage, in which the benefits of increased A/I Tech use have accrued via improved performance. The last column shows the increase in performance that was realized from the 4th quartile of use to the quartile of greatest benefit. In addition to the quartile analysis, correlation coefficients for each index and performance metric were calculated. These results, provided in Appendix F, are intended to supplement the quartile analysis methodology.

4.1 CII - Owners

Quartile analysis of performance outcomes and the use of A/I Tech, A Tech, and I Tech for CII owner projects is presented in Tables 4-1 to 4-3, respectively. As the technology use advances from the 4th quartile (indicating low use) to the 1st quartile (indicating high use), the outcome values should decrease, reflecting improved performance with increased technology use if performance and technology use are positively correlated. Examination of the relationships for A/I Tech reveals a general cost performance improvement with increased technology use, although it is not consistent quartile to quartile and lacks statistical significance. Owners reported a decrease of 1.9 % in project cost growth with more use of A/I Tech as measured by the improvement in cost growth from the 4th quartile to the 1st quartile of A/I Tech use. Similarly, there was a 4.5 %

improvement in procurement cost growth and a 5.9 % improvement in the procurement phase cost factor. As noted in many cases, improvements in performance quartile to quartile were not observed as IT use increased resulting in some perceived inconsistencies in the expected relationship. And in some cases, a decrease in performance can be observed as companies initiated use of new technologies when moving from the 4th quartile to the 3rd quartile of A/I Tech use. This suggests a performance penalty associated with a learning curve for new technologies; however, the learning curve effect is not as widely observed as had been in previous studies. From a research perspective, as well as that of the practitioner, consistent performance gains would be preferred with increased technology use; however, this may not be a reasonable expectation. Many factors beyond technology use affect project performance and those have not been considered in the analyses presented here. Failure to address the impacts of these factors and in many cases small samples may be attributing to the inconsistent patterns observed for some metrics.

The impact of A/I Tech use on schedule performance is more pronounced. As shown in Table 4-1, owners reported project schedule growth improvement of 17.3 % from lowest to highest A/I Tech use and this finding is statistically significant as shown in Appendix F. Schedules also became more predictable as shown by reductions in the Delta Project Schedule Growth metric. The reduction in Overall Project Duration may also suggest schedule compression with increased A/I Tech use. There is no measured improvement in the Procurement Phase Duration Factor. The lack of any measured improvement is designated by the entry of a dash "-" in the last column.

For safety performance, only DART is improved with more A/I Tech use. DART is an OSHA incidence rate based on the total number of days away and restricted cases.

Table 4-1. Correlation of A/I Tech Use with Project Outcomes – CII Owners

Performance Metrics[1]		A/I Technology Use (Low use ⟷ High use)				No use to Greatest Benefit[3]
		Investment stage		Benefit stage		
Name	n	4th	3rd	2nd	1st	
COST Project Cost Growth	86	0.007	-0.011	0.019*	-0.012	0.019
Delta Project Cost Growth	89	0.104	0.106	0.105	0.074	0.030
Procurement Phase Cost Growth[2]	40	-0.047*		-0.092		0.045
Procurement Phase Cost Factor[2]	48	0.205*		0.146		0.059
SCHEDULE Project Schedule Growth[+]	83	0.233*	0.078	0.111*	0.060	0.173
Delta Project Schedule Growth	86	0.289	0.143	0.144	0.130	0.153
Overall Project Duration (week)	89	149.7	107.3	109.0	117.2	40.7
Procurement Phase Duration Factor[2]	55	0.366*	0.444*	0.410*	0.419	-
SAFETY TRIR	70	0.883*	1.001	1.424*	0.909*	-
DART	51	0.112*	0.048*	0.089*	0.034*	0.078
CHANGES Change Cost Factor	81	0.077	0.091*	0.086	0.069	0.008
Change Schedule Factor	28	0.116*		0.124*		-
REWORK Rework Cost Factor	47	0.011*	0.007*	0.012*	0.019*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects) and C.T. data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies) per Appendix A.
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Tables 4-2 and 4-3 summarize correlations for performance outcomes and the use of A Tech and I Tech, respectively. The patterns observed in these tables are similar to those shown in Table 4-1.

Table 4-2 Correlation of A Tech Use with Project Outcomes – CII Owners

Performance Metrics[1]		Automation Technology Use: Low use ⟷ High use — Investment stage		Benefit stage		No use to Greatest Benefit[3]
Name	**n**	4th	3rd	2nd	1st	
COST Project Cost Growth	85	0.002	0.001	-0.004*	-0.001	0.006
Delta Project Cost Growth	88	0.109	0.094	0.102	0.085	0.024
Procurement Phase Cost Growth[2]	40	-0.022*		-0.111		0.089
Procurement Phase Cost Factor[2]	48	0.239*		0.126*		0.113
SCHEDULE Project Schedule Growth	82	0.148*	0.140*	0.099	0.077	0.071
Delta Project Schedule Growth	85	0.208	0.212	0.137	0.141	0.071
Overall Project Duration (week)	88	126.3	114.4	108.0	126.7	-
Procurement Phase Duration Factor[2]	55	0.384*	0.426*	0.426*	0.399*	-
SAFETY TRIR	69	1.128	0.563*	1.259*	1.293*	-
DART	50	0.086		0.056		0.030
CHANGES Change Cost Factor	80	0.094	0.071*	0.068	0.082	0.026
Change Schedule Factor	28	0.110*		0.132*		-
REWORK Rework Cost Factor	47	0.010		0.015		-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects) and C.T. data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies) per Appendix A.
+ Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Table 4-3 Correlation of I Tech Use with Project Outcomes – CII Owners

<table>
<tr><th colspan="2" rowspan="2">Performance Metrics[1]</th><th colspan="4">Integration Technology Use
Low use ←→ High use</th><th rowspan="3">No use to Greatest Benefit[3]</th></tr>
<tr><th colspan="2">Investment stage</th><th colspan="2">Benefit stage</th></tr>
<tr><th>Name</th><th>n</th><th>4th</th><th>3rd</th><th>2nd</th><th>1st</th></tr>
<tr><td><u>COST</u>
Project Cost Growth</td><td>85</td><td>0.026</td><td>-0.017</td><td>-0.009*</td><td>0.005</td><td>0.035</td></tr>
<tr><td>Delta Project Cost Growth</td><td>88</td><td>0.101</td><td>0.106</td><td>0.081*</td><td>0.091</td><td>0.020</td></tr>
<tr><td>Procurement Phase Cost Growth[2]</td><td>40</td><td colspan="2">-0.057</td><td colspan="2">-0.098*</td><td>0.041</td></tr>
<tr><td>Procurement Phase Cost Factor[2]</td><td>48</td><td colspan="2">0.181</td><td colspan="2">0.152</td><td>0.028</td></tr>
<tr><td><u>SCHEDULE</u>
Project Schedule Growth[+]</td><td>82</td><td>0.225*</td><td>0.104</td><td>0.056*</td><td>0.083</td><td>0.169</td></tr>
<tr><td>Delta Project Schedule Growth[+]</td><td>85</td><td>0.277*</td><td>0.152</td><td>0.095*</td><td>0.158</td><td>0.182</td></tr>
<tr><td>Overall Project Duration (week) [+]</td><td>88</td><td>167.0</td><td>97.9</td><td>134.2*</td><td>107.9</td><td>59.1</td></tr>
<tr><td>Procurement Phase Duration Factor[2]</td><td>55</td><td colspan="2">0.385</td><td colspan="2">0.438</td><td>-</td></tr>
<tr><td><u>SAFETY</u>
TRIR</td><td>70</td><td>0.965*</td><td>1.033</td><td>1.312*</td><td>0.974*</td><td>-</td></tr>
<tr><td>DART</td><td>51</td><td colspan="2">0.083</td><td colspan="2">0.051*</td><td>0.032</td></tr>
<tr><td><u>CHANGES</u>
Change Cost Factor</td><td>80</td><td>0.077</td><td>0.088</td><td>0.074</td><td>0.071</td><td>0.006</td></tr>
<tr><td>Change Schedule Factor</td><td>28</td><td colspan="2">0.124</td><td colspan="2">C.T.</td><td>-</td></tr>
<tr><td><u>REWORK</u>
Rework Cost Factor</td><td>47</td><td colspan="2">0.011</td><td colspan="2">0.015*</td><td>-</td></tr>
</table>

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects) and C.T. data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies) per Appendix A.
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

4.2 CII - Contractors

Quartile analysis of performance outcomes and the use of A/I Tech, A Tech, and I Tech for CII contractor projects is presented in Tables 4-4 through 4-6, respectively. Since there are only 45 contractor projects in the CII dataset, quartile analysis was not used as the sample size for each quartile is not adequate for analysis. Instead, the data are divided into two halves for characterization as investment and benefit stages.

Contractors reporting higher use of A/I Tech also reported 3.3 % better cost performance than low uses of the technologies. Contractors also reported benefits correlated with A/I Tech use in the procurement phase, although the benefit was less than that reported by owners. There is no measured improvement in the Delta Project Cost Growth metric. The lack of any measured improvement is designated by the entry of a dash "-" in the last column.

For the schedule performance, both investment stage and benefit stage have negative mean schedule growth values that are essentially the same indicating that contractors managed schedule performance well irrespective of technology use. Although the difference in schedule growth between investment and benefit stages lacks any practical significance at only 0.2 %, there may be some evidence to support schedule compression benefits. Overall project duration was less in the benefits stage than the investment stage suggesting the possibility of schedule compression.

For safety, change, and rework performance, there was no reported improvements with increased A/I Tech use. Small samples could be a factor here.

Table 4-4 Correlation of A/I Tech Use with Project Outcomes – CII Contractors

Performance Metrics[1]		A/I Technology Use (Low use ↔ High use)		No use to Greatest Benefit[3]
		Investment stage	Benefit stage	
Name	**n**	2nd	1st	
COST Project Cost Growth	41	-0.015	-0.048	0.033
Delta Project Cost Growth	40	0.081	0.092	-
Procurement Phase Cost Growth[2]	30	-0.038*	-0.064*	0.026
Procurement Phase Cost Factor[2]	30	0.331*	0.329*	0.002
SCHEDULE Project Schedule Growth	31	-0.013*	-0.011*	-
Delta Project Schedule Growth	42	0.083	0.077	0.006
Overall Project Duration (week)	40	93.5*	90.2	3.3
Procurement Phase Duration Factor[2]	28	0.565*	0.528*	0.037
SAFETY TRIR	27	0.382*	0.549*	-
DART	21	0.076*	0.084*	-
CHANGES Change Cost Factor	37	0.058*	0.065	-
Change Schedule Factor	16	0.117*	C.T.	-
REWORK Rework Cost Factor+	20	C.T.	0.014*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects) and C.T. data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies) per Appendix A.
+ Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Tables 4-5 and 4-6 show the correlations for A Tech and I Tech, respectively. As with owners, the results summarized in the tables are similar to the results in Table 4-4 with most of the benefits apparently coming from I Tech which appears to correlate with performance. I Tech was also especially beneficial in the procurement phase.

Table 4-5 Correlation of A Tech Use with Project Outcomes – CII Contractors

Performance Metrics[1]		Automation Technology Use Low use ⟷ High use		No use to Greatest Benefit[3]
		Investment stage	Benefit stage	
Name	**n**	2nd	1st	
COST Project Cost Growth+	41	-0.029	-0.035	0.006
Delta Project Cost Growth	40	0.077	0.097*	-
Procurement Phase Cost Growth[2]	30	-0.049*	-0.056*	0.008
Procurement Phase Cost Factor[2]	30	0.326*	0.334*	-
SCHEDULE Project Schedule Growth	31	-0.015*	-0.009*	-
Delta Project Schedule Growth	42	0.071	0.089	-
Overall Project Duration (week)	40	93.0	90.5	2.4
Procurement Phase Duration Factor[2]	28	0.555*	0.541*	0.014
SAFETY TRIR	27	0.434*	0.500*	-
DART	21	0.084*	0.077*	0.007
CHANGES Change Cost Factor	37	0.054*	0.069*	-
Change Schedule Factor	16	0.126*	C.T.	-
REWORK Rework Cost Factor+	20	C.T.	0.014*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects) and C.T. data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies) per Appendix A.
+ Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Table 4.6 Correlation of I Tech Use with Project Outcomes – CII Contractors

Performance Metrics[1]		Integration Technology Use (Low use ⟷ High use) Investment stage	Benefit stage	No use to Greatest Benefit[3]
Name	**n**	2nd	1st	
COST Project Cost Growth	41	-0.018	-0.045	0.027
Delta Project Cost Growth	40	0.090	0.083	0.007
Procurement Phase Cost Growth[2]	30	-0.044*	-0.061*	0.017
Procurement Phase Cost Factor[2]	30	0.319*	0.341*	-
SCHEDULE Project Schedule Growth	31	-0.017*	-0.008*	-
Delta Project Schedule Growth	42	0.089	0.072	0.017
Overall Project Duration (week)	40	91.5*	92.1	-
Procurement Phase Duration Factor[2]	28	0.601*	0.480*	0.121
SAFETY TRIR	27	0.388*	0.533*	-
DART	21	0.024*	0.131*	-
CHANGES Change Cost Factor	37	0.054*	0.068	-
Change Schedule Factor	16	0.117*	C.T.	-
REWORK Rework Cost Factor[+]	20	C.T.	0.012*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects) and C.T. data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies) per Appendix A.
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

From the tables above, it is clear that both owners and contractors report similar cost savings with increased use of technology as measured by the A/I Tech indices with most of these benefits being derived from integration technologies. The expected improvement is about 2 % for owner cost growth and 2 % to 3 % for cost predictability. Contractor cost growth benefits were about 3 %, with little improvement in predictability.

Schedule benefits correlated with technology use, however, they appear to accrue to the owners. Owners reported a 17 % improvement in schedule growth and more than a 20 % improvement in schedule compression. Although contractors report no noticeable improvement in schedule performance, this may be due to the already excellent schedule performance of the projects in the dataset. When performance is already excellent, there may be little additional benefit from added technology use.

The data revealed no correlation between the total recordable rate, TRIR, and A/I Tech use; however, there appear to be some benefits related to A/I Tech use and the DART rate, especially for owners. These findings may not be intuitive, but may be related to project size and observations noted with schedule performance. TRIR tends to remain fairly constant or is independent of project size, whereas DART rates increase with project size. A rather simple explanation for this may be that the more serious lost time cases (DART) can be avoided on smaller projects, but are more difficult to avoid for projects reporting very large work-hours. Thus the large number of DART rates at zero for smaller projects produces mean values near zero; however, as project size increases, zero lost workdays is increasingly difficult to achieve, and rates rise rather significantly. The less sensitive recordable rate (TRIR) remains more constant because even smaller projects are likely to have some recordable incidents. Since the DART is rising with project size, as is technology use, improvements in the rate correlated with technology use are more easily detected. When the rate remains constant, as with the TRIR, correlation with increasing technology use is more difficult to quantify. As with contractor schedule performance, when there is little to improve, the benefits are less apparent. For owners, a nearly 0.078 improvement in the DART was reported with increased A/I Tech use with both A Tech and I Tech contributing to the improvement.

4.3 Southeastern U.S. Contractors

Performance of the Southeastern U.S. Contractors is correlated with the IT Index to relate company performance and technology utilization. The analysis methodology used for CII data was applied to this dataset, with only one IT Index used to assess technology use. Table 4-7 summarizes the results. Since the number of data points, n, for each metric in the dataset is provided; there is no statistical warning indicator or confidentiality policy indicator provided. The data available are small in some cases, therefore the analysis is performed by halves rather than quartiles. Results from simple statistical correlation are provided in Appendix F to supplement the investment and benefit stage analysis.

Table 4-7. Correlation of IT Index Use with Company Performance

Performance Metrics		IT Use: Low use ↔ High use		Low use to Greatest Benefit
		Investment stage	Benefit stage	
Category	**n**	2nd	1st	
Percent on/under budget	69	80.729 (35)	82.809 (34)	2.080 (2.6 %)
Percent on/ahead of schedule+	70	73.375 (36)	85.265 (34)	11.890 (16.2 %)
Safety (EMR)	35	0.717 (16)	0.689 (19)	0.027 (3.8 %)
Percent Repeat Business	68	54.848 (33)	63.843 (35)	8.994 (16.4 %)
Profit as Percent of Sales	48	4.923 (30)	3.725 (18)	-

n indicates the number of companies.
+ Statistical significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the performance in the benefit stage is better than that in the investment stage.
* The percentage in the last column is calculated by
{(mean value of 1st)-(mean value of 2nd)}/(mean value of 2nd).

While the dataset and analyses are conceptually similar to CII's, the data are very different as documented in Chapter 3. The performance metrics measure cost, schedule, and safety as does CII's, but are defined such that higher values are better with the exception of EMR where lower numbers are better. Direct comparison between the results is not straight forward, but the underlying performance categories align and benefits from technology use are apparent. Other metrics addressing customer satisfaction assessed through repeat business and profitability are useful additions to the CII performance metrics. The analysis of the Southeastern U.S. Contractors dataset should be viewed as complementary and broadening for findings of technology impacts beyond those produced through the CII data. It samples a population of smaller firms than those contained in the CII data set and yet produces similar findings.

Of particular interest are the similarities in reported benefits to those of the CII owners. Cost savings were 2.6 % and schedule benefits were approximately 16 %, very much in line with CII owners. Also similar to the CII owners, the schedule benefits are statistically significant. Safety benefits as measured by improvement in the EMR are also similar to the improvements in the DART. While the underlying metrics are different and direct comparison is not reasonable, similar findings in the broader performance categories of cost, schedule, and safety are encouraging. Other benefits, not assessed by the CII data, include customer satisfaction, reporting a 16 % improvement with increased IT Index use.

4.4 Mapping Indices

4.4.1 Mapping Indices with CII Data

In addition to the three A/I Tech indices, three additional indices were developed as a result of the mapping work described in Chapter 2. The primary benefit obtained through the mappings was the identification of closely and somewhat related CII work functions facilitating development of special “mapped” A/I Tech indices which could be checked for improved correlations with project outcomes. The additional indices developed include a Procurement Index, and two Project Management Indices: one for closely related work functions and the other for all related work functions. The NIST business process management function Procurement had five CII task work functions mapped as closely-related; these CII task work functions were selected to comprise the mapped Procurement Index. The NIST business process management function Project Management had 9 CII task work functions mapped: 4 as closely-related and 5 somewhat-related. Project Management Indices were developed for both the closely related CII functions and all CII related functions. Following the mapping, each mapped index was separated into 6 distinct sub-indices: A/I Tech, A Tech, and I Tech for both owners and contractors.

All of these indices and their correlations are provided in Appendix E. After extensive analysis of the mapped indices it was concluded that the mapped indices produced results similar to the broader A/I Tech indices without overall significant correlation improvements. The mapped indices actually produced slightly more significant correlations for one index, however, given that the mappings were actually quite subjective and resulted in the elimination nearly half of the A/I Tech work functions from the analysis, they were dropped from the analysis in favor of the more broadly defined CII A/I Tech.

4.4.2 Mapping Indices Southeastern U.S. Contractors Data

Three indices were also developed with the data mapped from contractor firms in the Southeastern U.S. as described in Chapter 2. These indices included a Procurement Index and 2 Project Management Indices. Statistical correlation analyses were performed for each index with the results presented in Appendix F. Compared with IT Index, the mapping indices showed slightly more statistically significant correlations, but, the correlation coefficients were not improved over the IT Index.

5. CONCLUSIONS AND RECOMMENDATIONS

In this report, the impacts of information technology on project and firm performance in the construction industry are studied. Data are drawn from 139 projects in the CII Benchmarking & Metrics database and from 74 contractors in the Southeastern United States. Analysis of these datasets reveals some broad conclusions. First, increased IT use is generally correlated with improved performance. This is particularly true for schedule performance, although some lesser benefits are observed with cost and safety performance. Both the CII and Southeastern U.S. Contractors datasets show similar findings, although their sample populations, metrics, and IT work function questions vary greatly. These complementary findings strengthen the overall premise of this research that increased use of technology correlates with improved project performance as well as support the NIST GCR 04-867 findings that lack of interoperability contributes to significant expenses for the capital facilities industry (in particular, those costs incurred during design and construction).

Specific findings are that for CII member company projects, cost savings are on the order of 1 % to 3 %, and Southeastern U.S. Contractors benefited by 3 % with increased use of IT. Predictability, measured by the CII delta cost growth metric, showed a 2 % to 3 % benefit to owners, but none were observed by contractors. Schedule compression benefit to CII owners was observed at 17 % while Southeastern U.S. Contractors benefited by a 16 % improvement in schedule performance. Predictability for owners as measured by the CII delta schedule growth metric improved by 15 %. No schedule benefits were found for CII contractors, although it must be noted that the population of projects had uniformly good schedule performance and hence the schedule compression metric would not capture the benefits. No benefits were found for safety on CII projects, whereas Southeastern U.S. Contractors showed a 4 % improvement in their Experience Modification Rate (EMR). Customer satisfaction showed a 16 % improvement for Southeastern U.S. Contractors firms; no corresponding measurement exists for CII projects.

It must be noted that there is considerable variance in the datasets. IT is not the sole driver of project performance and as such it is difficult to clearly identify the relationship between project performance and IT utilization. This variance can be seen, for example, in the CII owner project analysis that is broken into quartiles of IT use. In many cases performance does not improve uniformly from lowest to highest use. This may be in some cases due to learning effects where there is a dip in performance after initial usage until firms learn better how to fully incorporate the power of new technologies. In other cases, the second quartile for owners shows mildly better than the first or highest quartile of IT use. It is possible that in the top quartiles the performance benefits are largely achieved and other project conditions create more meaningful differences in measured performance. Alternately, the costs of using IT at the highest level may incur costs that balance the gains. Further research is warranted to investigate and track the level of IT use and associated benefits over time.

Beyond the noise of individual metrics, most meaningful is the consistency of results across studies with different measurement methods, showing benefits in cost and schedule performance in particular. Other researchers have noted the difficulties of measuring any benefit to IT use (the "productivity paradox") and have further observed that important innovations have taken years for industry to fully and productively incorporate into their operations (Attewell 1996; Brynjolfsson 1993; King 1996). As the capital facilities industry is still in reasonably early stages of incorporating information technologies, considerable variation and noise is to be expected. Hence while the verdict on the impact of information technology on performance has not yet been delivered, it is reasonable to conclude that benefits do exist and are being observed by projects (at least within the design and construction phase) and companies involved on these projects. As such, the basic recommendation is that companies should continue to invest in these technologies.

Appendix A: Statistical Notes – CII Dataset

Confidentiality
When there were less than 10 projects available in a category or when less than 3 companies submitted the data, no statistical summaries are provided. This is consistent with the CII policy on confidentiality and in such cases the code "C.T." (Confidentiality Test) was inserted in the tables.

Statistical Warning Indicator
When there are less than 20 projects included in any table cell, an asterisk (*) follows the data value. This notation indicates that the data in that table cell should be interpreted with caution due to the small number of projects represented.

Removal of Statistical Outliers
Prior to performing the Task 2 statistical analyses, all outcome metrics values calculated were screened to remove statistical outliers. This step was incorporated to remove values so extreme that their inclusion would likely distort the statistical summaries produced. The technique used to identify statistical outliers was the same used to define outliers in most statistical texts. This is also the same definition used for outlier commonly used in the preparation of box and whisker plots. All values exceeding the 75th percentile value plus 1.5 times the inter-quartile range or those less than the 25th percentile value minus 1.5 times the inter-quartile range were excluded.

Appendix B: Metric Definitions

B.1 Performance Metric Formulas and Definitions – CII Dataset

Performance Metric Category: COST

Metric: ***Project Cost Growth***	**Formula:** $\dfrac{\text{Actual Total Project Cost - Initial Predicted Project Cost}}{\text{Initial Predicted Project Cost}}$
Metric: ***Delta Project Cost Growth***	**Formula:** | Project Cost Growth |
Metric: ***Project Budget Factor***	**Formula:** $\dfrac{\text{Actual Total Project Cost}}{\text{Initial Predicted Project Cost +Approved Changes}}$
Metric*:* ***Delta Project Budget Factor***	**Formula:** | 1- Project Budget Factor |
Metric: ***Phase Cost Factor*** *(Owner data only)*	**Formula:** $\dfrac{\text{Actual Phase Cost}}{\text{Actual Total Project Cost}}$
Metric: ***Phase Cost Growth*** *(Owner data only)*	**Formula:** $\dfrac{\text{Actual Phase Cost – Initial Predicted Phase Cost}}{\text{Initial Predicted Phase Cost}}$

Definition of Terms

Actual Total Project Cost:

- Owners –
  - All actual project cost from pre-project planning through startup
  - Exclude land costs but include in-house salaries, overhead, travel, etc.
- Contractors – Total cost of the final scope of work.

Initial Predicted Project Cost:

- Owners – Budget at the time of authorization.
- Contractors – Cost estimate used as the basis of contract award.

Actual Phase Cost:

- All costs associated with the project phase in question.
- See the Project Phase Table in Appendix C for phase definitions.

Initial Predicted Phase Cost:

- Owners – Budget at the time of authorization.
- Contractors – – Budget at the time of contract award.
- See the Project Phase Table in Appendix C for phase definitions.

Approved Changes:

- Estimated cost of owner-authorized changes.

Performance Metric Category: SCHEDULE

Metric: ***Project Schedule Growth***	**Formula:** $\dfrac{\text{Actual Total Proj. Duration - Initial Predicted Proj. Duration}}{\text{Initial Predicted Proj. Duration}}$
Metric: ***Delta Project Schedule Growth***	**Formula:** **| Project Schedule Growth |**
Metric: ***Project Schedule Factor***	**Formula:** $\dfrac{\text{Actual Total Project Duration}}{\text{Initial Predicted Project Duration + Approved Changes}}$
Metric: ***Delta Project Schedule Factor***	**Formula:** **| 1- Project Schedule Factor |**
Metric: ***Phase Schedule Growth***	**Formula:** $\dfrac{\text{Actual Phase Duration}}{\text{Actual Overall Project Duration}}$
Metric: ***Phase Duration Factor*** *(Owner data only)*	**Formula:** $\dfrac{\text{Actual Phase Duration – Initial Predicted Phase Duration}}{\text{Initial Predicted Phase Duration}}$
Metric: ***Overall Project Duration***	Actual Overall Project Duration (weeks)
Metric: ***Design-Startup Duration***	Actual Total Project Duration (weeks)
Metric: ***Construction Phase Duration***	Actual Construction Phase Duration (weeks)

Definition of Terms

<u>Actual Total Project Duration</u>:
<u>(Detail Design through Start-up)</u>

- Owners – Duration from beginning of detail design to turnover to user.
- Contractors - Total duration for the final scope of work from mobilization to completion.

<u>Actual Overall Project Duration</u>:
<u>(Pre-project Planning through Start-up)</u>

- Unlike Actual Total Duration, Actual Overall Duration also includes time consumed for the Pre-Project Planning Phase.

<u>Actual Phase Duration</u>:

- Actual total duration of the project phase in question. See the Project Phase Table in Appendix C for phase definitions.

<u>Initial Predicted Project Duration:</u>

- Owners – Predicted duration at the time of authorization.
- Contractors - The contractor's duration estimate at the time of contract award.

<u>Approved Changes</u>

- Estimated duration of owner-authorized changes.

Performance Metric Category: SAFETY

Metric: ***Total Recordable Incident Rate (TRIR)***	**Formula:** $\frac{\text{Total Number of Recordable Cases x 200,000}}{\text{Total Site Work-Hours}}$
Metric: ***Dart Rate (LWCIR)***	**Formula:** $\frac{\text{Total Number of DART Cases x 200,000}}{\text{Total Site Work-Hours}}$

Definition of Terms

- Recordable Cases: All work-related deaths and illnesses, and those work-related injuries which result in: death, loss of consciousness, restriction of work or motion, transfer to another job, or require medical treatment beyond first aid.
- DART Cases: Incidents resulting in days away from work, restricted activity, or transfer.

Performance Metric Category: CHANGES

Metric: ***Change Cost Factor***	**Formula:** $\frac{\text{Total Cost of Changes}}{\text{Actual Total Project Cost}}$
Metric: ***Change Schedule Factor***	**Formula:** $\frac{\text{Total Schedule of Changes}}{\text{Actual Total Project Duration}}$

Definition of Terms

Total Cost of Changes:

- Total cost impact of scope and project development changes.

Total Schedule of Changes:

- Total schedule impact of scope and project development changes.

Actual Total Project Cost:

- Owners –
  - All actual project cost from pre-project planning through startup
  - Exclude land costs but include in-house salaries, overhead, travel, etc.
- Contractors – Total cost of the final scope of work.

Actual Total Project Duration:
(Detail Design through Start-up)

- Owners – Duration from beginning of detail design to turnover to user.
- Contractors - Total duration for the final scope of work from mobilization to completion.

Performance Metric Category: REWORK

Metric: ***Rework Cost Factor***	**Formula:** $\dfrac{\text{Total Direct Cost of Field Rework}}{\text{Actual Construction Phase Cost}}$
Definition of Terms	
• Total Direct Cost of Field Rework: Total direct cost of field rework regardless of initiating cause.	• Actual Construction Phase Cost: All costs associated with the construction phase. See the Project Phase Table in Appendix C for construction phase definition.

B.2 Performance Metric Formulas and Definitions – Southeastern U.S. Contractors Dataset

B.2.1 Schedule Performance

For projects closed in the last 2 fiscal years, how often were these projects delivered on/ahead of schedule? (i.e., 40 % of the time)

$$\frac{Number\ \ of\ \ projects\ \ completed\ \ on\,or\,ahead\ \ of\ \ schedule}{Total\ \ number\ \ of\ \ projects} \times 100\,\%$$

B.2.2 Cost Performance

For projects closed in the last 2 fiscal years, how often were these projects delivered on/under budget? (i.e., 40 % of the time)

$$\frac{Number\ \ of\ \ projects\ \ completed\ \ on\,or\,under\ \ budget}{Total\ \ number\ \ of\ \ projects} \times 100\,\%$$

B.3.3 Safety Performance (EMR)

EMR stands for Experience Modification Rate. EMR is a workers' compensation insurance measure of past safety experience. The equation to calculate EMR is

$$EMR = \frac{Actual\ Losses}{Expected\ Losses}$$

B.3.4 Customer Satisfaction

Customer satisfaction is measured by the percentage of repeated business customers? (i.e., 20 % of customers return for a repeat business with the firm)

B.3.5 Profit

What is your firm's Net Profit after tax as a percent of Total Sales? (for the last fiscal year available)

Appendix C: Project Phase Definitions – CII Dataset

Project Phase Definition Table

Project Phase	**Start/Stop**	Typical Activities & Products	Typical Cost Elements
Front End Planning Typical Participants: • Owner Personnel • Planning Consultants • Constructability Consultant • Alliance / Partner	**Start: Defined Business Need that requires facilities** **Stop: Total Project Budget Authorized**	• Options Analysis • Life-cycle Cost Analysis • Project Execution Plan • Appropriation Submittal Pkg • P&IDs and Site Layout • Project Scoping • Procurement Plan • Arch. Rendering	• Owner Planning Team Personnel Expenses • Consultant Fees & Expenses • Environmental Permitting Costs • Project Manager / Construction Manager Fees • Licensor Costs
Detail Design Typical Participants: • Owner Personnel • Design Contractor • Constructability Expert • Alliance / Partner	**Start: Design Basis** **Stop: Release of all approved drawings and specs for construction (or last package for fast-track)**	• Drawing & Spec Preparation • Bill of Material Preparation • Procurement Status • Sequence of Operations • Technical Review • Definitive Cost Estimate	• Owner Project Management Personnel • Designer Fees • Project Manager / Construction Manager Fees
Procurement Typical Participants: • Owner Personnel • Design Contractor • Alliance / Partner	**Start: Procurement Plan for Engineered Equipment** **Stop: All engineered equipment has been delivered to site**	• Supplier Qualification • Supplier Inquiries • Bid Analysis • Purchasing • Engineered Equipment • Transportation • Supplier QA/QC	• Owner Project Management Personnel • Project/Construction Manager Fees • Procurement & Expediting Personnel • Engineered Equipment • Transportation • Shop QA/QC

Project Phase Definition Table (Cont.)

Project Phase	**Start/Stop**	Typical Activities & Products	Typical Cost Elements
Construction Typical Participants: • Owner Personnel • Design Contractor (Inspection) • Construction Contractor and its Subcontractors	**Start: Beginning of continuous substantial construction activity** **Stop: *Mechanical Completion***	• Set Up Trailers • Site Preparation • Procurement of Bulks • Issue Subcontracts • Construction Plan for Methods/Sequencing • Build Facility & Install Engineered Equipment • Complete Punchlist • Demobilize Construction Equipment	• Owner Project Management Personnel • Project Manager / Construction Manager Fees • Building Permits • Inspection QA/QC • Construction Labor, Equipment & Supplies • Bulk Materials • Construction Equipment • Contractor Management Personnel • Warranties
Start-up / Commissioning Note: Not usually applicable to infrastructure or building projects Typical Participants: • Owner personnel • Design Contractor • Construction Contractor • Training Consultant • Equipment Suppliers	**Start: *Mechanical Completion*** **Stop: Custody transfer to user/operator (steady state operation)**	• Testing Systems • Training Operators • Documenting Results • Introduce Feedstocks and Obtain First Product • Hand-off to User/Operator • Operating System • Functional Facility • Warranty Work	• Owner Project Management Personnel • Project Manager / Construction Manager Fees • Consultant Fees & Expenses • Operator Training Expenses • Wasted Feedstocks • Supplier Fees

Appendix D: Calculation of A/I Technology and Other Indices

D.1 Scoring the A/I Tech, Automation Tech, and Integration Tech Indices

This appendix provides formulas and procedures for calculating the A/I Tech and other indices for the CII dataset. Figure D-1 provides a detailed example for score calculation. In the figure, shading indicates the respondent's assessment of the degree of technology use.

The equation to calculate A/I Tech is

$$A/I\,TechIndex = \frac{(\#of\,'1')\times 0 + (\#of\,'2')\times 0.25 + (\#of\,'3')\times 0.50 + (\#of\,'4')\times 0.75 + (\#of\,'5')\times 1}{\#of\ \ questions\ \ answered}\times 10$$

Projects with responses to less than 50 % of the questions are not scored. Indices scores can range from 0 to 10 with higher scores indicating more technology use.

For the A Tech index, only the questions for automation technology are considered and for the I Tech index, only the questions for integration technology are considered. Hence, there are 26 questions scored for A/I Tech index and 13 questions each for A Tech and I Tech.

Figure D-1 Sample Calculation – CII A/I Tech, A Tech, and I Tech Indices

	Use Levels: No Use				Full Use			
Automation	**1**	**2**	**3**	**4**	**5**	**N/A**	**Unknown**	**Score**
Business Planning and Analysis	0	0.25	0.50	0.75	1.00	-	-	1.00
Conceptual Definition & Design	0	0.25	0.50	0.75	1.00	-	-	0.75
Project (Discipline) Definition & Facility Design	0	0.25	0.50	0.75	1.00	-	-	0.75
Supply Management	0	0.25	0.50	0.75	1.00	-	-	0.50
Project Management								
Coordination System	0	0.25	0.50	0.75	1.00	-	-	1.00
Communication System	0	0.25	0.50	0.75	1.00	-	-	1.00
Cost System	0	0.25	0.50	0.75	1.00	-	-	1.00
Schedule System	0	0.25	0.50	0.75	1.00	-	-	1.00
Quality System	0	0.25	0.50	0.75	1.00	-	-	0.75
Off-Site/Pre-Construction	0	0.25	0.50	0.75	1.00	-	-	0.75
Construction	0	0.25	0.50	0.75	1.00	-	-	0.75
As-Built Documentation	0	0.25	0.50	0.75	1.00	-	-	1.00
Facility Start-Up & Life Cycle Support	0	0.25	0.50	0.75	1.00	-	-	0.50
Automation Technology score subtotal								***10.75***

Figure D-1 Sample Calculations – CII A/I Tech, A Tech, and I Tech Indices – continued

	Use Levels							
	No Use				Full Use			
Integration	**1**	**2**	**3**	**4**	**5**	**N/A**	**Unknown**	**Score**
Business Planning and Analysis	0	0.25	0.50	0.75	1.00	-	-	1.00
Conceptual Definition & Design	0	0.25	0.50	0.75	1.00	-	-	0.75
Project (Discipline) Definition & Facility Design	0	0.25	0.50	0.75	1.00	-	-	1.00
Supply Management	0	0.25	0.50	0.75	1.00	-	-	0.75
Project Management								
Coordination System	0	0.25	0.50	0.75	1.00	-	-	1.00
Communication System	0	0.25	0.50	0.75	1.00	-	-	1.00
Cost System	0	0.25	0.50	0.75	1.00	-	-	1.00
Schedule System	0	0.25	0.50	0.75	1.00	-	-	1.00
Quality System	0	0.25	0.50	0.75	1.00	-	-	0.75
Off-Site/Pre-Construction	0	0.25	0.50	0.75	1.00	-	-	0.75
Construction	0	0.25	0.50	0.75	1.00	-	-	0.75
As-Built Documentation	0	0.25	0.50	0.75	1.00	-	-	1.00
Facility Start-Up & Life Cycle Support	0	0.25	0.50	0.75	1.00	-	-	0.75

Integration Technology score subtotal	***11.5***
Total: Automation Technology score + Integration Technology score	***22.25***
Divide total & subtotals by the number of questions answered for indices scores: 26 max for A/I Tech & 13 max for A Tech & I Tech	
A/I Tech Index: (22.25/26)*10	***8.56***
A Tech Index: (10.75/13)*10	***8.27***
I Tech Index: (11.5/13)*10	***8.85***

D.2 Scoring the Mapping Indices

The mapping indices are developed based on the mappings performed for Task 1. Mapping indices are calculated similar to the A/I Tech index; however, they only take mapped CII work functions into account.

Figure D-2 shows the procedure for calculating the Procurement index. The NIST business process management function “Procurement” has five mapped CII work functions:

- Project Definition & Facility Design
- Supply Management
- Cost System
- Schedule System
- Off-Site/Pre-Construction

In Figure D-2, only the five scores for the mapped functions are taken into account. Therefore, a total of 10 (5 automation and 5 integration) work functions were used for the calculation of Procurement A/I Tech with 5 work functions used for calculation of A Tech and 5 used for calculation of I Tech.

The NIST business process function “Project Management” was also used for developing mapping indices. For this process function, two indices were developed, one with only “closely-related” CII work functions and the other with all mapped CII work functions. The calculation procedure is similar to the one for the Procurement index.

Figure D-2 Sample Calculations – CII Procurement Mapping Indices for A/I Tech, A Tech, and I Tech

	Use Levels: No Use				Full Use			
Automation	**1**	**2**	**3**	**4**	**5**	**N/A**	**Unknown**	**Score**
Business Planning and Analysis	0	0.25	0.50	0.75	1.00	-	-	
Conceptual Definition & Design	0	0.25	0.50	0.75	1.00	-	-	
Project (Discipline) Definition & Facility Design	0	0.25	0.50	0.75	1.00	-	-	0.75
Supply Management	0	0.25	0.50	0.75	1.00	-	-	0.50
Project Management								
Coordination System	0	0.25	0.50	0.75	1.00	-	-	
Communication System	0	0.25	0.50	0.75	1.00	-	-	
Cost System	0	0.25	0.50	0.75	1.00	-	-	1.00
Schedule System	0	0.25	0.50	0.75	1.00	-	-	1.00
Quality System	0	0.25	0.50	0.75	1.00	-	-	
Off-Site/Pre-Construction	0	0.25	0.50	0.75	1.00	-	-	0.75
Construction	0	0.25	0.50	0.75	1.00	-	-	
As-Built Documentation	0	0.25	0.50	0.75	1.00	-	-	
Facility Start-Up & Life Cycle Support	0	0.25	0.50	0.75	1.00	-	-	

Subtotal of A Tech score from the five mapped Procurement CII work functions	***4.00***

Figure D-2 Sample Calculations – CII Procurement Mapping Indices for A/I Tech, A Tech, and I Tech - continued

	Use Levels: No Use				Full Use			
Integration	**1**	**2**	**3**	**4**	**5**	**N/A**	**Unknown**	**Score**
Business Planning and Analysis	0	0.25	0.50	0.75	1.00	-	-	
Conceptual Definition & Design	0	0.25	0.50	0.75	1.00	-	-	
Project (Discipline) Definition & Facility Design	0	0.25	0.50	0.75	1.00	-	-	1.00
Supply Management	0	0.25	0.50	0.75	1.00	-	-	0.75
Project Management								
Coordination System	0	0.25	0.50	0.75	1.00	-	-	
Communication System	0	0.25	0.50	0.75	1.00	-	-	
Cost System	0	0.25	0.50	0.75	1.00	-	-	1.00
Schedule System	0	0.25	0.50	0.75	1.00	-	-	1.00
Quality System	0	0.25	0.50	0.75	1.00	-	-	
Off-Site/Pre-Construction	0	0.25	0.50	0.75	1.00	-	-	0.75
Construction	0	0.25	0.50	0.75	1.00	-	-	
As-Built Documentation	0	0.25	0.50	0.75	1.00	-	-	
Facility Start-Up & Life Cycle Support	0	0.25	0.50	0.75	1.00	-	-	

Subtotal of I Tech score from the five Procurement mapped CII work functions	***4.5***
Total: A/I Tech score	***8.5***
Divide total & subtotals by the number of questions answered for indices scores: 10 max for A/I Tech & 5 max for A Tech & I Tech and multiply by 10	
Procurement index A/I Tech: (8.5/10)*10	***8.5***
Procurement index A Tech: (4.0/5)*10	***8.0***
Procurement index I Tech: (4.5/5)*10	***9.0***

D.3 Scoring the IT index for Southeastern U.S. Contractors Dataset

The calculation of IT index is similar to the A/I Technology index. The main difference between the two indices is that the IT index is based on 48 work functions which represent four phases, procurement, construction management, construction execution, and maintenance and startup, whereas the A/I Tech index is based on 26 work functions which represent Automation and Integration Technologies. The second difference is that A/I Technology index is based on five possible responses for the degree of technology use. IT use, on the other hand, is based on three options.

The equation for calculating IT index is

$$ITindex = \left[\frac{Sum\ of\ work\ functions\ scores}{(Total\ \#\ of\ work\ functions - \#\ of\ "N/A"\ responses - \#\ of\ "Don't\ know"\ responses)} - 1\right] \times 5$$

Similar to A/I Tech index, companies providing less than 50 % of scoreable responses are not scored. The IT index, also similar to the A/I Tech index, has a score range from 0 to 10, with higher scores indicating more IT use.

Appendix E: Quartile Analyses for Mapping Indices

This appendix presents and discusses quartile analyses of the CII mapping indices. The table formats used in this appendix are the same as in Chapter 4. The first two columns list the performance metrics and the number of projects available for analysis. The third through sixth columns of the tables (for quartile analysis or third and fourth columns for analysis by halves) show the mean value for each performance metric for each mapping index. For quartile analyses, the 3rd and 4th quartiles are characterized as the investment stage and the 1st and 2nd quartiles are characterized as the benefit stage. The last column shows the increase in performance that was realized from the 4th quartile of use to the quartile of greatest benefit. The lack of any measured improvement is designated by the entry of a dash "-" in the last column.

E.1 Procurement Index

Tables E-1 to E-3 summarize the quartile analyses for Procurement mapping indices for CII owners. Development of the indices is presented in Appendix D. Procurement Indices are developed based on the CII work functions mapped with the NIST "Procurement" business process management function (see Table 2-6). These CII work functions are

- 3. Project Definition & Facility Design
- 4. Supply Management
- 5-3. Cost System
- 5-4. Schedule System
- 6. Off-Site/Pre-Construction

In general findings from the quartile analyses for the Procurement indices were similar to findings from the general (non-mapped) A/I Tech analyses. Overall project cost performance improvements of 1 % to 2 % were observed and most of these are attributed to integration technologies. Procurement cost metrics showed modest improvements as well.

Schedule growth improvement of about 16 % was reported which is very close to the general owner's A/I Tech value of 17.3 %. Schedule compression was improved though by the Procurement A/I tech index; compression with the Procurement index was approximately 42 % vs. 27 % for the general A/I Tech index.

Safety benefits of A/I Tech use were only observed in the DART rate and these benefits were almost twice those reported for the general A/I Tech index.

Tables E-2 and E-3 depict the results of quartile analyses from the Procurement A Tech index and I Tech index for owners, respectively. These tables follow closely patterns observed with the general A/I Tech indices in which most benefits come from the integration index.

Table E-1. Correlation of Procurement A/I Tech Use with Project Outcomes – CII Owners

Performance Metrics[1]		A/I Technology Use: Low use ↔ High use				No use to Greatest Benefit[3]
		Investment stage		Benefit stage		
Name	n	4th	3rd	2nd	1st	
COST Project Cost Growth	86	0.009	-0.011	0.005*	-0.003	0.012
Delta Project Cost Growth	89	0.098	0.090	0.115	0.085	0.013
Procurement Phase Cost Growth[2]	40	-0.044*		-0.094		0.050
Procurement Phase Cost Factor[2]	48	0.187*		0.157		0.030
SCHEDULE Project Schedule Growth[+]	83	0.228*	0.062	0.111	0.067	0.161
Delta Project Schedule Growth	86	0.270	0.157	0.132	0.138	0.138
Overall Project Duration (week)[+]	89	157.0	111.5	91.3	123.3	65.7
Procurement Phase Duration Factor[2]	55	0.391*	0.383*	0.403*	0.439*	-
SAFETY TRIR	70	1.066*	0.964	1.150*	1.028*	-
DART	51	0.104		0.029		0.075
CHANGES Change Cost Factor	81	0.085	0.072*	0.088*	0.075	0.010
Change Schedule Factor	28	0.118*		0.123*		-
REWORK Rework Cost Factor[+]	47	0.010*	0.005*	0.018*	0.019*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects).
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Table E-2. Correlation of Procurement A Tech Use with Project Outcomes – CII Owners

Performance Metrics[1]		Automation Technology Use: Low use ↔ High use				No use to Greatest Benefit[3]
		Investment stage		Benefit stage		
Name	**n**	4th	3rd	2nd	1st	
COST Project Cost Growth	85	-0.012	0.004	0.010*	-0.002*	-
Delta Project Cost Growth	88	0.079	0.107	0.115	0.092	-
Procurement Phase Cost Growth[2]	40	-0.040*		-0.107		0.067
Procurement Phase Cost Factor[2]	48	0.206		0.136		0.070
SCHEDULE Project Schedule Growth	82	0.120	0.138	0.105*	0.088	0.031
Delta Project Schedule Growth	85	0.159	0.203	0.174*	0.149	0.010
Overall Project Duration (week)	88	130.1	108.5	112.3	125.4	17.8
Procurement Phase Duration Factor[2]	55	0.425*	0.433*	0.362*	0.409*	0.062
SAFETY TRIR	69	1.134	0.776	1.198*	1.245*	-
DART	50	0.086		0.056		0.030
CHANGES Change Cost Factor	80	0.082	0.083	0.071*	0.083	-
Change Schedule Factor	28	0.119*		0.121*		-
REWORK Rework Cost Factor	47	0.003*	0.019*	0.008*	0.017*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects).
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Table E-3. Correlation of Procurement I Tech Use with Project Outcomes – CII Owners

Performance Metrics[1]		Integration Technology Use: Low use ↔ High use				No use to Greatest Benefit[3]
		Investment stage		Benefit stage		
Name	n	4th	3rd	2nd	1st	
COST Project Cost Growth	85	-0.003	0.008	-0.010*	0.001	0.007
Delta Project Cost Growth	88	0.100	0.100	0.112*	0.081	0.019
Procurement Phase Cost Growth[2]	40	-0.071		-0.078		0.007
Procurement Phase Cost Factor[2]	48	0.188		0.151		0.037
SCHEDULE Project Schedule Growth[+]	82	0.219*	0.096	0.056*	0.101	0.163
Delta Project Schedule Growth[+]	85	0.269	0.153	0.088*	0.177	0.181
Overall Project Duration (week) [+]	88	154.8	107.5	124.5*	104.2	50.6
Procurement Phase Duration Factor[2]	55	0.407*	0.362*	0.387*	0.454*	-
SAFETY TRIR	70	0.873*	1.073*	1.450*	0.887*	-
DART	51	0.114		0.011		0.103
CHANGES Change Cost Factor	80	0.071	0.086	0.090*	0.070*	0.001
Change Schedule Factor	28	0.117*		C.T.		-
REWORK Rework Cost Factor[+]	47	0.007		0.021		-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects).
C.T. Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies).
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Tables E-4 to E-6 summarize the quartile analyses for Procurement mapping indices for CII contractors. Development of the indices is presented in Appendix D. Procurement Indices are developed based on the CII work functions mapped with the NIST "Procurement" business process management function. These CII work functions are

- 3. Project Definition & Facility Design
- 4. Supply Management
- 5-3. Cost System
- 5-4. Schedule System
- 6. Off-Site/Pre-Construction

In general findings from the quartile analyses for the Procurement indices were similar to findings from the general A/I Tech analyses. Overall project cost performance improvements of 1 % to 4 % were observed and most of these are attributed to integration technologies.

Negligible schedule growth improvements were reported which is very different from owner's reported benefits. Modest schedule compression safety benefits were reported.

Table E-4. Correlation of Procurement A/I Tech Use with Project Outcomes – CII Contractors

Performance Metrics[1]		A/I Technology Use Low use ↔ High use Investment stage	Benefit stage	No use to Greatest Benefit[3]
Name	**n**	2nd	1st	
COST Project Cost Growth	41	-0.026	-0.038	0.012
Delta Project Cost Growth	40	0.082	0.090	-
Procurement Phase Cost Growth[2]	30	-0.077*	-0.034*	-
Procurement Phase Cost Factor[2]	30	0.367*	0.306*	0.061
SCHEDULE Project Schedule Growth	31	-0.015*	-0.009*	-
Delta Project Schedule Growth	42	0.076	0.083	-
Overall Project Duration (week)	40	96.2*	87.9	8.3
Procurement Phase Duration Factor[2]	28	0.548*	0.550*	-
SAFETY TRIR	27	0.351*	0.562*	-
DART	21	0.084*	0.077*	0.007
CHANGES Change Cost Factor	37	0.052*	0.070	-
Change Schedule Factor	16	0.122*	C.T.	-
REWORK Rework Cost Factor+	20	C.T.	0.014*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use.
* Statistical warning indicator (less than 20 projects).
C.T. Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies).
+ Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the performance in the benefit stage is better than that in the investment stage.

Table E-5. Correlation of Procurement A Tech Use with Project Outcomes – CII Contractors

Performance Metrics[1]		Automation Technology Use (Low use ↔ High use)		No use to Greatest Benefit[3]
		Investment stage	Benefit stage	
Name	**n**	2nd	1st	
COST Project Cost Growth	41	-0.023	-0.041	0.018
Delta Project Cost Growth	40	0.080	0.093	-
Procurement Phase Cost Growth[2]	30	-0.064*	-0.043*	-
Procurement Phase Cost Factor[2]	30	0.369*	0.304*	0.065
SCHEDULE Project Schedule Growth	31	-0.019*	-0.005*	-
Delta Project Schedule Growth	42	0.085	0.076	0.009
Overall Project Duration (week)	40	94.0	89.6*	4.4
Procurement Phase Duration Factor[2]	28	0.541*	0.560*	-
SAFETY TRIR	27	0.332*	0.578*	-
DART	21	0.084*	0.077*	0.007
CHANGES Change Cost Factor	37	0.059*	0.064*	-
Change Schedule Factor	16	0.142*	C.T.	-
REWORK Rework Cost Factor+	20	C.T.	0.014*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use.
* Statistical warning indicator (less than 20 projects).
C.T. Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies).
+ Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the performance in the benefit stage is better than that in the investment stage.

Table E-6. Correlation of Procurement I Tech Use with Project Outcomes – CII Contractors

Performance Metrics[1]		Integration Technology Use (Low use ↔ High use)		No use to Greatest Benefit[3]
		Investment stage	Benefit stage	
Name	**n**	2nd	1st	
COST Project Cost Growth	40	-0.016	-0.057	0.041
Delta Project Cost Growth	39	0.089	0.080*	0.009
Procurement Phase Cost Growth[2]	30	-0.064*	-0.044*	-
Procurement Phase Cost Factor[2]	30	0.366*	0.302*	0.064
SCHEDULE Project Schedule Growth	31	-0.020*	-0.004*	-
Delta Project Schedule Growth	41	0.085	0.067	0.018
Overall Project Duration (week)	39	101.6*	84.4	17.2
Procurement Phase Duration Factor[2]	28	0.594*	0.489*	0.105
SAFETY TRIR	27	0.310*	0.595*	-
DART	21	0.076*	0.084*	-
CHANGES Change Cost Factor	36	0.054*	0.062	-
Change Schedule Factor	15	0.107*	C.T.	-
REWORK Rework Cost Factor	20	C.T.	0.013*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use.
* Statistical warning indicator (less than 20 projects).
C.T. Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies).
Shading indicates the performance in the benefit stage is better than that in the investment stage.

E.2 Project Management Index – Closely Related Work Functions

This section presents the results from mapped Project Management (PM) indices for closely related work functions. There were two PM indices developed; PM with closely-related work functions (PMC) and PM with all mapped work functions (PMA).

PMC indices were developed with the CII work functions which mapped as closely related with the NIST Project Management business process management function (see Table 2-6). These CII work functions are

- 5-3. Cost System
- 5-4. Schedule System
- 5-5. Quality System
- 7. Construction

Benefits shown in Tables E-7 to E-9 are generally less than those shown in Tables 4-1 to 4-3 developed with all work functions. For the PMC analyses cost benefits were only about 1 %, although procurement cost benefits were as high as 7 %. Schedule benefits were reduced as well with the PMC values at about 11 % to 12 %. Some schedule compression was again apparent with most of the benefits attributed to integration.

Table E-7. Correlation of PM Closely Related A/I Tech Use with Project Outcomes – CII Owners

Performance Metrics[1]		A/I Technology Use: Low use ⟷ High use				No use to Greatest Benefit[3]
		Investment stage		Benefit stage		
Name	n	4th	3rd	2nd	1st	
COST Project Cost Growth	86	0.005	-0.013*	0.011*	-0.005	0.010
Delta Project Cost Growth	89	0.114	0.069*	0.120	0.080	-
Procurement Phase Cost Growth[2]	40	-0.067*		-0.081		0.014
Procurement Phase Cost Factor[2+]	48	0.214*		0.138		0.075
SCHEDULE Project Schedule Growth[+]	83	0.185	0.100*	0.087*	0.076	0.109
Delta Project Schedule Growth	86	0.232	0.124*	0.203	0.123	0.109
Overall Project Duration (week)	89	140.6	112.8*	100.3	123.6	40.3
Procurement Phase Duration Factor[2]	55	0.429		0.391		0.038
SAFETY TRIR	70	0.902	1.114*	1.228*	1.028*	-
DART	51	0.027*	0.232*	0.000*	0.049*	0.027
CHANGES Change Cost Factor	81	0.080	0.078*	0.096*	0.069	0.011
Change Schedule Factor	28	0.118*		0.122*		-
REWORK Rework Cost Factor	47	0.017*	0.004*	0.010*	0.019*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects).
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Table E-8. Correlation of PM Closely Related A Tech Use with Project Outcomes – CII Owners

Performance Metrics[1]		Automation Technology Use (Low use ⟷ High use)				No use to Greatest Benefit[3]
		Investment stage		Benefit stage		
Name	n	4th	3rd	2nd	1st	
COST Project Cost Growth	85	0.002	-0.019*	-0.007	0.015	-
Delta Project Cost Growth	88	0.100	0.096*	0.093	0.101	0.007
Procurement Phase Cost Growth[2]	40	-0.054*		-0.092		0.038
Procurement Phase Cost Factor[2+]	48	0.185*	0.243*	0.143*	0.125*	0.060
SCHEDULE Project Schedule Growth	82	0.140	0.205*	0.019*	0.105	0.121
Delta Project Schedule Growth	85	0.173	0.242*	0.155	0.141	0.032
Overall Project Duration (week)	88	126.4	110.9*	99.7	135.8	-
Procurement Phase Duration Factor[2]	55	0.405*	0.491*	0.391*	0.364*	0.041
SAFETY TRIR	69	1.068	0.644*	1.377*	1.194*	-
DART	50	0.086		0.056		0.030
CHANGES Change Cost Factor	80	0.080	0.086*	0.084*	0.072	0.008
Change Schedule Factor	28	0.118*		0.123*		-
REWORK Rework Cost Factor	47	0.010		0.014		-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects).
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Table E-9. Correlation of PM Closely Related I Tech Use with Project Outcomes – CII Owners

Performance Metrics[1]		Integration Technology Use (Low use ⟷ High use): Investment stage		Integration Technology Use (Low use ⟷ High use): Benefit stage		No use to Greatest Benefit[3]
Name	**n**	4th	3rd	2nd	1st	
COST Project Cost Growth	85	-0.002		0.004		-
Delta Project Cost Growth	88	0.101	0.102	0.092*	0.092	0.009
Procurement Phase Cost Growth[2]	40	-0.079		-0.071*		-
Procurement Phase Cost Factor[2]	48	0.202		0.132		0.070
SCHEDULE Project Schedule Growth[+]	82	0.193	0.096	0.053*	0.097	0.140
Delta Project Schedule Growth[+]	85	0.230	0.151	0.179*	0.145	0.085
Overall Project Duration (week)[+]	88	149.1	98.9	133.7	116.7	32.4
Procurement Phase Duration Factor[2]	55	0.410		0.406		0.004
SAFETY TRIR	70	0.963		1.195		-
DART	51	0.103		0.013*		0.090
CHANGES Change Cost Factor	80	0.077	0.083	0.081*	0.074	0.003
Change Schedule Factor	28	0.115*		C.T.		-
REWORK Rework Cost Factor	47	0.009		0.018		-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects).
C.T. Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies)
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Tables E-10 to E-12 summarize the results from Project Management Closely Related (PMC) indices for CII contractors for A/I Tech, A Tech, and I Tech, respectively. The PMC A/I Tech index for contractors showed the greatest cost savings in terms of project cost growth. Similar to other CII indices, PMC indices for contractors do not show many schedule benefits. Safety benefits were not found.

Table E-10. Correlation of PM Closely Related A/I Tech Use with Project Outcomes – CII Contractors

Performance Metrics[1]		A/I Technology Use (Low use ⟷ High use)		No use to Greatest Benefit[3]
		Investment stage	Benefit stage	
Name	**n**	2nd	1st	
COST Project Cost Growth	41	-0.004	-0.061	0.057
Delta Project Cost Growth	40	0.087	0.086*	-
Procurement Phase Cost Growth[2]	30	-0.055*	-0.051*	-
Procurement Phase Cost Factor[2]	30	0.348*	0.318*	0.030
SCHEDULE Project Schedule Growth	31	-0.014*	-0.010*	-
Delta Project Schedule Growth	42	0.101	0.059	0.042
Overall Project Duration (week)	40	93.7	89.9	3.8
Procurement Phase Duration Factor[2]	28	0.565*	0.528*	0.037
SAFETY TRIR	27	0.275*	0.623*	-
DART	21	0.076*	0.084*	-
CHANGES Change Cost Factor	37	0.065*	0.058*	0.007
Change Schedule Factor	16	0.120*	C.T.	-
REWORK Rework Cost Factor[+]	20	C.T.	0.014*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use.
* Statistical warning indicator (less than 20 projects).
C.T. Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies).
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the performance in the benefit stage is better than that in the investment stage.

Table E-11. Correlation of PM Closely Related A Tech Use with Project Outcomes – CII Contractors

Performance Metrics[1]		Automation Technology Use (Low use ⟷ High use): Investment stage	Automation Technology Use (Low use ⟷ High use): Benefit stage	No use to Greatest Benefit[3]
Name	**n**	2nd	1st	
COST Project Cost Growth[+]	41	-0.027	-0.037	0.010
Delta Project Cost Growth	40	0.081	0.092*	-
Procurement Phase Cost Growth[2]	30	-0.060*	-0.046*	-
Procurement Phase Cost Factor[2]	30	0.344*	0.320*	0.024
SCHEDULE Project Schedule Growth	31	-0.018*	-0.006*	-
Delta Project Schedule Growth	42	0.081	0.079	0.002
Overall Project Duration (week)	40	92.6	90.9*	1.7
Procurement Phase Duration Factor[2]	28	0.530*	0.579*	-
SAFETY TRIR	27	0.423*	0.511*	-
DART	21	0.076*	0.084*	-
CHANGES Change Cost Factor	37	0.059*	0.065*	-
Change Schedule Factor	16	0.137*	C.T.	-
REWORK Rework Cost Factor[+]	20	C.T.	0.014*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use.
* Statistical warning indicator (less than 20 projects).
C.T. Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies).
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the performance in the benefit stage is better than that in the investment stage.

Table E-12. Correlation of PM Closely Related I Tech Use with Project Outcomes – CII Contractors

Performance Metrics[1]		Integration Technology Use (Low use ↔ High use)		No use to Greatest Benefit[3]
		Investment stage	Benefit stage	
Name	**n**	2nd	1st	
COST Project Cost Growth	41	-0.016	-0.051*	0.035
Delta Project Cost Growth	40	0.083	0.091*	-
Procurement Phase Cost Growth[2]	30	-0.051*	-0.054*	0.003
Procurement Phase Cost Factor[2]	30	0.342*	0.319*	0.023
SCHEDULE Project Schedule Growth	31	-0.015*	-0.009*	-
Delta Project Schedule Growth	42	0.089	0.070	0.019
Overall Project Duration (week)	40	97.9	85.1*	12.9
Procurement Phase Duration Factor[2]	28	0.570*	0.512*	0.058
SAFETY TRIR	27	0.286*	0.634*	-
DART	21	0.070*	C.T.	-
CHANGES Change Cost Factor	37	0.061*	0.062*	-
Change Schedule Factor	16	0.112*	C.T.	-
REWORK Rework Cost Factor[+]	20	C.T.	0.014*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use.
* Statistical warning indicator (less than 20 projects).
C.T. Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies).
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the performance in the benefit stage is better than that in the investment stage.

E.3 Project Management with All Mapped Work Functions

PMA indices were developed based on all of the CII work functions that mapped with the NIST Project Management business process management function (see Table 2-6). These CII work functions are:

- 4. Supply Management
- 5-1. Coordination System
- 5-2. Communication System
- 5-3. Cost System
- 5-4. Schedule System
- 5-5. Quality System
- 6. Off-Site/Pre-Construction
- 7. Construction
- 8. As-Built Documentation

Tables E-13 to E-15 present the quartile analyses with PMA for CII owners. The tables show improvements in cost predictability up to 3.5 %; however, no cost growth benefits were determined. The two procurement phase cost metrics also showed benefits of more technology use, but not a sufficient amount to warrant use of the PMA indices over the general A/I Tech indices. Schedule benefits were in line with those of the broader A/I Tech metrics.

Table E-13. Correlation of PM All Mapped A/I Tech Use with Project Outcomes – CII Owners

Performance Metrics[1]		A/I Technology Use: Low use ⟷ High use				No use to Greatest Benefit[3]
		Investment stage		Benefit stage		
Name	**n**	4th	3rd	2nd	1st	
COST Project Cost Growth	86	0.010	-0.016	0.012*	-0.003	-
Delta Project Cost Growth	89	0.116	0.090	0.101*	0.081	0.035
Procurement Phase Cost Growth[2]	40	-0.062*		-0.084		0.022
Procurement Phase Cost Factor[2]	48	0.217*		0.136		0.081
SCHEDULE Project Schedule Growth[+]	83	0.236*	0.070	0.103*	0.066	0.170
Delta Project Schedule Growth		0.278	0.140	0.148*	0.133	0.145
Overall Project Duration (week)	89	140.0	115.0	102.2	123.4	37.8
Procurement Phase Duration Factor[2]	55	0.374*	0.414*	0.391*	0.439*	-
SAFETY TRIR	70	0.911	0.991	1.365*	1.028*	-
DART	51	0.104		0.029		0.075
CHANGES Change Cost Factor	81	0.091	0.071	0.082*	0.075	0.016
Change Schedule Factor	28	0.110*		0.132*		-
REWORK Rework Cost Factor	47	0.009		0.016*		-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects).
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Table E-14. Correlation of PM All Mapped A Tech Use with Project Outcomes – CII Owners

Performance Metrics[1]		Automation Technology Use: Low use ↔ High use — Investment stage		Benefit stage		No use to Greatest Benefit[3]
Name	**n**	4th	3rd	2nd	1st	
COST Project Cost Growth	85	-0.005	0.007*	0.000	-0.001	-
Delta Project Cost Growth	88	0.110	0.089*	0.103	0.085	0.025
Procurement Phase Cost Growth[2]	40	-0.053*		-0.093		0.040
Procurement Phase Cost Factor[2]	48	0.213		0.136		0.077
SCHEDULE Project Schedule Growth	82	0.144	0.179*	0.065*	0.077	0.079
Delta Project Schedule Growth	85	0.196	0.231*	0.135	0.141	0.061
Overall Project Duration (week)	88	126.1	111.5*	108.9	126.7	-
Procurement Phase Duration Factor[2]	55	0.372*	0.476*	0.386*	0.399*	-
SAFETY TRIR	69	1.094	0.625*	1.213*	1.293*	-
DART	50	0.089		0.054		0.035
CHANGES Change Cost Factor	80	0.092	0.073*	0.066*	0.082	0.026
Change Schedule Factor	28	0.112*		0.128*		-
REWORK Rework Cost Factor	47	0.011		0.014		-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects).
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Table E-15. Correlation of PM All Mapped I Tech Use with Project Outcomes – CII Owners

Performance Metrics[1]		Integration Technology Use (Low use ↔ High use): Investment stage		Benefit stage		No use to Greatest Benefit[3]
Name	**n**	4th	3rd	2nd	1st	
COST Project Cost Growth	85	-0.001		0.003		-
Delta Project Cost Growth	88	0.102		0.090		0.012
Procurement Phase Cost Growth[2]	40	-0.067		-0.085*		0.017
Procurement Phase Cost Factor[2]	48	0.194		0.138		0.056
SCHEDULE Project Schedule Growth[+]	82	0.145		0.072		0.073
Delta Project Schedule Growth[+]	85	0.267*	0.146	0.131*	0.153	0.136
Overall Project Duration (week)[+]	88	165.6	97.3	143.4*	108.7	56.9
Procurement Phase Duration Factor[2]	55	0.397		0.421		-
SAFETY TRIR	70	1.037		1.063		-
DART	51	0.100		0.014*		0.086
CHANGES Change Cost Factor	80	0.074	0.089	0.083	0.071	0.003
Change Schedule Factor	28	0.113*		C.T.		-
REWORK Rework Cost Factor	47	0.009		0.018*		-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use (4th quartile).
* Statistical warning indicator (less than 20 projects).
C.T. Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies).
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

Tables E-16 to E-18 summarize Project Management All Mapped work functions (PMA) indices for CII contractors. Cost savings were almost the same among all three indices (A/I Tech, A Tech, and I Tech) and were similar to savings with the broader indices. Schedule benefits were minor and not significant.

Table E-16. Correlation of PM All Mapped A/I Tech Use with Project Outcomes – CII Contractors

Performance Metrics[1]		A/I Technology Use (Low use ⟷ High use)		No use to Greatest Benefit[3]
		Investment stage	Benefit stage	
Name	**n**	2nd	1st	
COST Project Cost Growth	40	-0.015	-0.044	0.029
Delta Project Cost Growth	39	0.081	0.090*	-
Procurement Phase Cost Growth[2]	29	-0.038*	-0.057*	0.019
Procurement Phase Cost Factor[2]	29	0.331*	0.330*	0.001
SCHEDULE Project Schedule Growth	30	-0.013*	-0.012*	-
Delta Project Schedule Growth	41	0.083	0.081	0.002
Overall Project Duration (week)	39	93.5*	93.2	0.3
Procurement Phase Duration Factor[2]	28	0.565*	0.528*	0.037
SAFETY TRIR	27	0.382*	0.549*	-
DART	21	0.076*	0.084*	-
CHANGES Change Cost Factor	36	0.058*	0.067*	-
Change Schedule Factor	16	0.117*	C.T.	-
REWORK Rework Cost Factor[+]	19	C.T.	0.015*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use.
* Statistical warning indicator (less than 20 projects).
C.T. Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies).
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the performance in the benefit stage is better than that in the investment stage.

Table E-17. Correlation of PM All Mapped A Tech Use with Project Outcomes – CII Contractors

Performance Metrics[1]		Automation Technology Use (Low use ↔ High use): Investment stage	Benefit stage	No use to Greatest Benefit[3]
Name	**n**	2nd	1st	
COST Project Cost Growth[+]	40	-0.018	-0.043*	0.025
Delta Project Cost Growth	39	0.081	0.091*	-
Procurement Phase Cost Growth[2]	29	-0.049*	-0.049*	-
Procurement Phase Cost Factor[2]	29	0.350*	0.314*	0.036
SCHEDULE Project Schedule Growth	30	-0.018*	-0.006*	-
Delta Project Schedule Growth	41	0.081	0.083	-
Overall Project Duration (week)	39	92.6	94.2*	-
Procurement Phase Duration Factor[2]	28	0.541*	0.560*	-
SAFETY TRIR	27	0.434*	0.500*	-
DART	21	0.084*	0.077*	0.007
CHANGES Change Cost Factor	36	0.061*	0.064*	-
Change Schedule Factor	16	0.140*	C.T.	-
REWORK Rework Cost Factor[+]	19	C.T.	0.015*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use.
* Statistical warning indicator (less than 20 projects).
C.T. Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies).
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the performance in the benefit stage is better than that in the investment stage.

Table E-18. Correlation of PM All Mapped I Tech Use with Project Outcomes – CII Contractors

Performance Metrics[1]		Integration Technology Use (Low use ⟷ High use): Investment stage	Benefit stage	No use to Greatest Benefit[3]
Name	**n**	2nd	1st	
COST Project Cost Growth	38	-0.023*	-0.048*	0.025
Delta Project Cost Growth	37	0.090*	0.080*	0.010
Procurement Phase Cost Growth[2]	30	-0.053*	-0.047*	-
Procurement Phase Cost Factor[2]	30	0.340*	0.309*	0.031
SCHEDULE Project Schedule Growth	30	-0.017*	-0.008*	-
Delta Project Schedule Growth[+]	39	0.085*	0.066	0.019
Overall Project Duration (week)	37	94.2*	98.4*	-
Procurement Phase Duration Factor[2]	28	0.576*	0.518*	0.058
SAFETY TRIR	27	0.388*	0.533*	-
DART	21	0.024*	0.131*	-
CHANGES Change Cost Factor	34	0.052*	0.067*	-
Change Schedule Factor	15	0.117*	C.T.	-
REWORK Rework Cost Factor[+]	19	C.T.	0.013*	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
[3] Maximum potential improvement from no use.
* Statistical warning indicator (less than 20 projects).
C.T. Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies).
[+] Statistically significant correlation between the performance metric and the technology use. See Appendix F.
Shading indicates the performance in the benefit stage is better than that in the investment stage.

Comparing the results from PMC indices and PMA indices; for owners' cost and schedule predictability, PMA indices showed more benefits of technology use than PMC indices. On the other hand, PMC indices showed more benefit for owners' schedule performance in the procurement phase.

Tables E-19 and E-20 summarizes all results from the mapping indices for CII owners and contractors, respectively. In addition, the results from general indices using all of CII work functions are also compared in the tables.

As shown, the results from general indices are similar to the results from mapping indices. If there is no benefit in the result from general indices, the result from mapping indices also indicates little or no benefit.

Tables E-19 and E-20 are also helpful for summarizing findings. For the CII owners, surprisingly, the results from the two procurement phase cost metrics show that the benefit from A Tech was greater than that from I Tech. In the schedule performance, the degree of correlation of technology use and schedule performance was much higher than that of technology use and cost performance. Specifically, I Tech shows higher benefits for the three overall schedule performance metrics, project schedule growth, delta project schedule growth, and overall project duration. Also, I Tech shows higher benefits for safety performance in terms of DART. All indices show little or no benefits for change performance in terms of change cost factor and no benefits in terms of change schedule factor and rework performance in terms of rework cost factor. More data are required to confirm this finding.

Table E-20 shows that CII contractors achieved more cost savings from I Tech than A Tech. A Tech was not helpful in improving cost predictability and I Tech had little or no benefit for cost predictability. For schedule performance, all indices report no benefits in terms of project schedule growth. For schedule predictability, I Tech was helpful and the benefit was about 2 %, whereas A Tech showed little or no benefit. Also, I Tech was beneficial for schedule compression in procurement phase.

Table E-19. Summary of Quartile Analyses with Mapping Indices – CII Owners

Performance Metrics	General Indices[1]			Mapping Indices		
	A/I Tech	A Tech	I Tech	A/I Tech	A Tech	I Tech
COST Project Cost Growth	1.9 %	0.6 %	3.5 %	None to 1.2 %	None	None to 0.7 %
Delta Project Cost Growth	3.0 %	2.4 %	2.0 %	None to 3.5 %	None to 2.5 %	0.9 % to 1.9 %
Procurement Phase Cost Growth	4.5 %	8.9 %	4.1 %	1.4 % to 5.0 %	3.8 % to 6.7 %	None to 1.7 %
Procurement Phase Cost Factor	5.9 %	11.3 %	2.8 %	3.0 % to 8.1 %	6.0 % to 7.7 %	3.7 % to 7.0 %
SCHEDULE Project Schedule Growth	17.3 %	7.1 %	16.9 %	10.9 % to 17.0 %	3.1 % to 12.1 %	7.3 % to 16.3 %
Delta Project Schedule Growth	15.3 %	7.1 %	18.2 %	10.9 % to 14.5 %	1.0 % to 6.1 %	8.5 % to 18.1 %
Overall Project Duration (weeks)	40.7 weeks	None	59.1 weeks	37.8 weeks to 65.7 weeks	None to 17.8 weeks	32.4 weeks to 56.9 weeks
Procurement Phase Duration Factor	None	None	None	None to 3.8%	None to 6.2 %	None to 0.4 %
SAFETY TRIR	None	None	None	None	None	None
DART	7.8 %	3.0 %	3.2 %	2.7 % to 7.5 %	3.0 % to 3.5 %	8.6 % to 10.3 %
CHANGES Change Cost Factor	0.8 %	2.6 %	0.6 %	1.0 % to 1.6 %	None to 2.6 %	0.1 % to 0.3 %
Change Schedule Factor	None	None	None	None	None	None
REWORK Rework Cost Factor	None	None	None	None	None	None

[1] Indices using all of CII work functions and the results are from Tables 4-1 to 4-3.

Table E-20. Summary of Quartile Analyses with Mapping Indices – CII Contractors

Performance Metrics	General Indices[1]			Mapping Indices		
	A/I Tech	A Tech	I Tech	A/I Tech	A Tech	I Tech
COST Project Cost Growth	3.3 %	0.6 %	2.7 %	1.2 % to 5.7 %	1.0 % to 2.5 %	2.5 % to 4.1 %
Delta Project Cost Growth	None	None	0.7 %	None	None	None to 1.0%
Procurement Phase Cost Growth	2.6 %	0.8 %	1.7 %	None to 1.9 %	None	None to 0.3 %
Procurement Phase Cost Factor	0.2 %	None	None	0.1 % to 6.1 %	2.4 % to 6.5 %	2.3 % to 6.4 %
SCHEDULE Project Schedule Growth	None	None	None	None	None	None
Delta Project Schedule Growth	0.6 %	None	1.7 %	None to 4.2 %	None to 0.9 %	1.8 % to 1.9 %
Overall Project Duration (weeks)	3.3 weeks	2.4 weeks	None	0.3 weeks to 8.3weeks	None to 4.4weeks	None to 17.2weeks
Procurement Phase Duration Factor	3.7 %	1.4 %	12.1 %	None to 3.7 %	None	5.8 % to 10.5 %
SAFETY TRIR	None	None	None	None	None	None
DART	None	0.7 %	None	None to 0.7 %	None to 0.7 %	None
CHANGES Change Cost Factor	None	None	None	None to 0.7 %	None	None
Change Schedule Factor	None	None	None	None	None	None
REWORK Rework Cost Factor	None	None	None	None	None	None

[1] Indices using all of CII work functions and the results are from Tables 4-4 to 4-6.

Appendix F: Statistical Correlations between the A/I Tech and IT Indices and Performance

Statistical correlations between all A/I Tech and IT indices and performance metrics are provided in this appendix. All values in the tables are correlation coefficients and are provided to supplement the quartile analysis. For the CII performance metrics, negative values indicate better performance. Since higher values of technology use indices mean higher use of technology, negative correlation coefficients between technology use indices and CII performance metrics are expected. For the performance metrics of Southeastern U.S. Contractors dataset, higher values of performance metrics indicate better performance, except for the safety performance (EMR). Therefore, positive correlation coefficient between the IT use indices and company performance metrics is expected.

As assumed, most of the correlation coefficient values in the CII dataset were negative. Further, relationships showing higher benefits in quartile analysis show statistically significance at the level of 10 % significance (p=0.1). One exemption for this occurred for the rework cost factor metric, specifically from the CII contractor data. From quartile analysis, there was no benefit of more technology use to improve this metric. However, the statistical correlations between the metric and most of technology use indices for contractors indicate that there was positive correlation between them, which means more technology use increases cost involving change. It is a surprising result, however, it should be noted that the sample size was small (about 20). More data are required for a better assessment.

F.1 A/I Tech Using All CII Work Functions

F.1.1 Owners

Performance Metrics	A/I Technology	Automation Technology	Integration Technology
COST Project Cost Growth	-0.034	0.000	-0.063
Delta Project Cost Growth	-0.091	-0.095	-0.095
Procurement Phase Cost Growth	0.008	-0.095	0.089
Procurement Phase Cost Factor	-0.168	-0.214	-0.113
SCHEDULE Project Schedule Growth	-0.184	-0.131	-0.214
Delta Project Schedule Growth	-0.164	-0.131	-0.181
Overall Project Duration (week)	-0.167	-0.006	-0.272
Procurement Phase Duration Factor	0.014	-0.057	0.066
SAFETY TRIR	-0.055	-0.035	-0.077
DART	-0.122	-0.123	-0.112
CHANGES Change Cost Factor	-0.135	-0.120	-0.104
Change Schedule Factor	0.093	0.140	0.036
REWORK Rework Cost Factor	0.213	0.183	0.205

Shading indicates p-value is lower than 0.1.

F.1.2 Contractors

Performance Metrics	A/I Technology	Automation Technology	Integration Technology
COST Project Cost Growth	-0.241	-0.284	-0.153
Delta Project Cost Growth	-0.010	0.189	-0.226
Procurement Phase Cost Growth	-0.129	-0.173	-0.056
Procurement Phase Cost Factor	0.137	0.150	0.117
SCHEDULE Project Schedule Growth	0.149	0.126	0.157
Delta Project Schedule Growth	-0.205	-0.158	-0.221
Overall Project Duration (week)	-0.078	-0.020	-0.137
Procurement Phase Duration Factor	-0.014	0.147	-0.205
SAFETY TRIR	0.108	0.077	0.132
DART	0.142	0.135	0.145
CHANGES Change Cost Factor	0.095	0.078	0.121
Change Schedule Factor	-0.026*	-0.093*	0.043*
REWORK Rework Cost Factor	0.451	0.477	0.391

Shading indicates p-value is lower than 0.1.
* Statistical warning indicator (sample size less than 20).

F.2 Mapping Indices

F.2.1 Procurement

F.2.1.1 Owners

Performance Metrics	A/I Technology	Automation Technology	Integration Technology
COST Project Cost Growth	-0.007	0.038	-0.052
Delta Project Cost Growth	-0.028	0.011	-0.083
Procurement Phase Cost Growth	-0.005	-0.102	0.063
Procurement Phase Cost Factor	-0.141	-0.154	-0.125
SCHEDULE Project Schedule Growth	-0.203	-0.136	-0.242
Delta Project Schedule Growth	-0.157	-0.112	-0.181
Overall Project Duration (week)	-0.187	-0.020	-0.295
Procurement Phase Duration Factor	-0.007	-0.081	0.048
SAFETY TRIR	-0.044	-0.028	-0.067
DART	-0.133	-0.145	-0.120
CHANGES Change Cost Factor	-0.106	-0.097	-0.073
Change Schedule Factor	0.017	0.060	-0.008
REWORK Rework Cost Factor	0.264	0.224	0.250

Shading indicates p-value is lower than 0.1.

F.2.1.2 Contractors

Performance Metrics	A/I Technology	Automation Technology	Integration Technology
COST Project Cost Growth	-0.213	-0.242	-0.166
Delta Project Cost Growth	-0.031	0.121	-0.230
Procurement Phase Cost Growth	-0.070	-0.105	-0.023
Procurement Phase Cost Factor	-0.014	0.035	-0.059
SCHEDULE Project Schedule Growth	0.207	0.179	0.226
Delta Project Schedule Growth	-0.130	-0.094	-0.175
Overall Project Duration (week)	-0.135	-0.085	-0.174
Procurement Phase Duration Factor	0.036	0.173	-0.150
SAFETY TRIR	0.148	0.148	0.145
DART	0.096	0.098	0.092
CHANGES Change Cost Factor	0.054	0.021	0.101
Change Schedule Factor	-0.039*	-0.105*	-0.014*
REWORK Rework Cost Factor	0.439	0.459	0.374

Shading indicates p-value is lower than 0.1.
* Statistical warning indicator (sample size less than 20).

F.2.2 Project Management Only with Closely-related Work Functions

F.2.2.1 Owners

Performance Metrics	A/I Technology	Automation Technology	Integration Technology
COST Project Cost Growth	0.004	0.025	-0.011
Delta Project Cost Growth	-0.062	-0.067	-0.071
Procurement Phase Cost Growth	0.035	-0.033	0.094
Procurement Phase Cost Factor	-0.244	-0.246	-0.214
SCHEDULE Project Schedule Growth	-0.203	-0.136	-0.247
Delta Project Schedule Growth	-0.167	-0.114	-0.204
Overall Project Duration (week)	-0.125	0.029	-0.232
Procurement Phase Duration Factor	-0.071	-0.137	-0.012
SAFETY TRIR	0.021	0.039	-0.015
DART	-0.046	-0.062	-0.053
CHANGES Change Cost Factor	-0.083	-0.072	-0.052
Change Schedule Factor	0.008	0.099	-0.076
REWORK Rework Cost Factor	0.229	0.211	0.214

Shading indicates p-value is lower than 0.1.

F.2.2.2 Contractors

Performance Metrics	A/I Technology	Automation Technology	Integration Technology
COST Project Cost Growth	-0.215	-0.270	-0.121
Delta Project Cost Growth	-0.025	0.124	-0.175
Procurement Phase Cost Growth	-0.053	-0.100	-0.001
Procurement Phase Cost Factor	0.023	0.079	-0.025
SCHEDULE Project Schedule Growth	0.097	0.166	0.017
Delta Project Schedule Growth	-0.143	-0.117	-0.140
Overall Project Duration (week)	-0.182	-0.103	-0.249
Procurement Phase Duration Factor	0.053	0.184	-0.109
SAFETY TRIR	0.148	0.063	0.218
DART	0.138	0.123	0.147
CHANGES Change Cost Factor	-0.068	-0.025	-0.090
Change Schedule Factor	-0.084*	-0.149*	0.004*
REWORK Rework Cost Factor	0.478	0.506	0.434

Shading indicates p-value is lower than 0.1.
* Statistical warning indicator (sample size less than 20).

F.2.3 Project Management with All Mapped Work Functions

F.2.3.1 Owners

Performance Metrics	A/I Technology	Automation Technology	Integration Technology
COST Project Cost Growth	-0.023	0.006	-0.046
Delta Project Cost Growth	-0.095	-0.100	-0.096
Procurement Phase Cost Growth	0.019	-0.085	0.095
Procurement Phase Cost Factor	-0.196	-0.236	-0.147
SCHEDULE Project Schedule Growth	-0.211	-0.141	-0.251
Delta Project Schedule Growth	-0.172	-0.124	-0.199
Overall Project Duration (week)	-0.156	0.012	-0.272
Procurement Phase Duration Factor	0.004	-0.062	0.045
SAFETY TRIR	-0.043	-0.011	-0.083
DART	-0.101	-0.094	-0.108
CHANGES Change Cost Factor	-0.123	-0.105	-0.103
Change Schedule Factor	0.084	0.147	0.014
REWORK Rework Cost Factor	0.210	0.172	0.219

Shading indicates p-value is lower than 0.1.

F.2.3.2 Contractors

Performance Metrics	A/I Technology	Automation Technology	Integration Technology
COST Project Cost Growth	-0.250	-0.304	-0.199
Delta Project Cost Growth	-0.032	0.166	-0.216
Procurement Phase Cost Growth	-0.110	-0.172	-0.042
Procurement Phase Cost Factor	0.130	0.164	0.046
SCHEDULE Project Schedule Growth	0.160	0.149	0.146
Delta Project Schedule Growth	-0.200	-0.169	-0.287
Overall Project Duration (week)	-0.083	0.001	-0.081
Procurement Phase Duration Factor	-0.008	0.154	-0.199
SAFETY TRIR	0.109	0.061	0.151
DART	0.148	0.122	0.168
CHANGES Change Cost Factor	0.057	0.048	0.111
Change Schedule Factor	-0.092*	-0.161*	-0.063*
REWORK Rework Cost Factor	0.523*	0.553*	0.460*

Shading indicates p-value is lower than 0.1.
* Statistical warning indicator (sample size less than 20).

F.3 Southeastern U.S. Contractors Dataset

Index	Schedule	Cost	Safety (EMR)	Customer Satisfaction	Profit
IT Use	0.248	0.123	-0.182	0.186	-0.114
Procurement Index	0.221	0.012	-0.167	0.153	-0.045
Project Management I	0.228	0.191	-0.175	0.240	-0.159
Project Management II	0.271	0.232	-0.201	0.235	-0.197

Shading indicates p-value is lower than 0.1.

Appendix G: References

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